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Optimization of CO_2 Laser Parameters for Wood Cutting

Lyubomir Lazov, Pavels Narica, Janis Valiniks, Antons Pacejs, Hristina Deneva, Dainis Klavins
Rezekne Academy of Technologies
Faculty of Engineering
Rezekne, Latvia
Lyubomir.Lazov@rta.lv

Abstract. By taking advantage of the best characteristics of wood, modern production methods can offer hard wearing and ecological solutions in industrial construction, house building, machinery construction, furniture manufacturing, transport and many other industries. Laser cutting process is an alternative choice to prepare the final shape of wood parts. Materials like wood have good laser light absorption of wavelength 10600 nm. In this paper a CO2 laser system with a maximum continuous-wave output power of 150 W is described and used in studying laser cutting process of wood materials. Cut depth is evaluated with variation of values of laser power and cutting speed. Additionally, optimal values of parameters for laser cutting of different wood plate thicknesses are determined and graphs are created showing the results.

Keywords:** CO_2 **laser, laser cutting, laser parameters optimization, wood.

I. INTRODUCTION

Lasers become more widespread by the day and are used by the industry more often. It can be observed that lasers replace other industrial machines and systems that people are accustomed to. Lasers are commonly used to weld, cut, mark, engrave different types of materials. There are a lot of reasons and evidence about laser materials processing advantages, and in this paper particular case of laser wood cutting is described in more detail. In general, the development of modern laser cutting technology occupies one of the leading positions compared with other materials processing methods [7].

Due to high power densities lasers can produce it is possible to achieve different kinds of macro-, micro-, and even nano- processing of materials. Mainly, laser is used for processing of such materials as metals, semiconductors, leather, different alloys, plastics, rubber, ceramics, wood etc. Laser cutting technology has quite a lot of advantages in comparison with other cutting equipment, i.e., clean cut, cutting of extremely fine contour and various thicknesses of materials as well as combinations thereof using only a single operation. Contactless treatment results in insignificant deformation of the material and high accuracy [1].

The aim of this paper was to determine relationship between the cut depth and laser parameters by performing analysis of obtained measurements during preliminary experimental investigation. As a result, options for optimization of laser parameters for wood cutting using CO2 laser were considered.

II. METHODOLOGY

A. Materials

Material which was studied is spruce cross laminated timber (CLT) panel. Fig. 1 shows a schematic view of a CLT panel configuration. A cross-section of a CLT element has at least three glued layers of boards that are finger-jointed using structural adhesive and placed in orthogonally alternating orientation to the neighboring layers. Lumber is visually-graded or machine stress-rated and is kiln dried. [4].

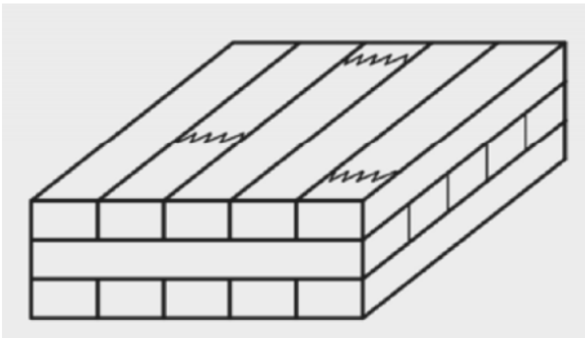

Fig. 1. CLT panel configuration [8]

Humidity of 13% +/-3% for boards of cross laminated timber (X-Lam) was set in the factory before packaging the panels. The humidity was

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estimated by electrical resistance method as it is shown in Fig. 2.

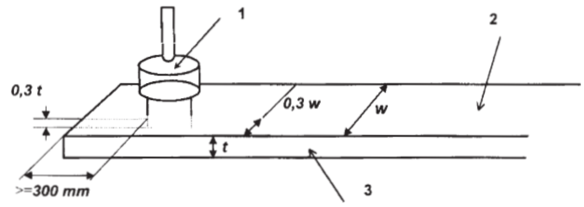

Fig. 2. Method of measureming humidity of board by electrical resistance, where 1 – hammer electrode, 2 – face, 3 – edge, t – thickness, w - width [9]

In panel production process timber sample was planed and subjected to pressure of 8 bar for 100 minutes. 60 mm thick panel was used for samples, consisting of three layers of crosswise compound, with board thickness of 20 mm. After all, CLT panel was cut into samples with 160 mm x 160 mm x 30 mm size as it is shown in Fig. 3.

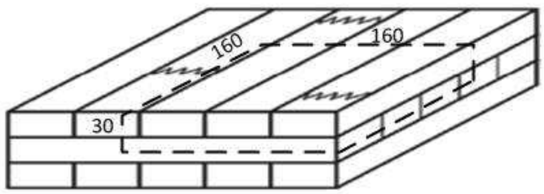

Fig. 3. Cut samples from CLT panel

B. Experimental set-up

In this study CHANXAN CW-1325 CO2 continuous-wave laser system with wavelength of 10060 nm was used. Schematic view of experimental set-up is shown in Fig. 4.

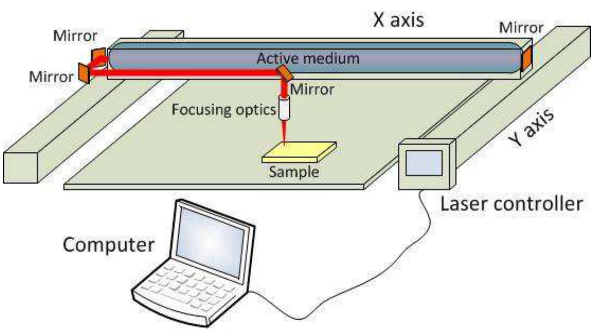

Fig. 4. Schematic view of experimental set-up

Laser system characteristics are shown in Table I.

Table I.
CHANXAN CW-1325 characteristics

Laser type	CO2 glass tube
Wavelength λ [nm]	10600
Laser power P [W]	0 - 150
Cutting area [mm]	2500 × 1300
Scanning speed [mm/s]	1 - 400
Cooling type	Water Colling
Assisted gas	Air
Focal lens diameter [mm]	19
Focus distance [mm]	63.5
Focal spot diameter [μm]	~60

There are two main modes of laser scanning provided by the laser system - raster mode and vector mode (Fig. 2). Raster mode (Fig. 5 - A) traces the laser beam across the surface in a back-and-forth motion and is good for engraving. Vector mode (Fig. 5. - P) follows the path of the outline of the shape and is good for cutting [2].

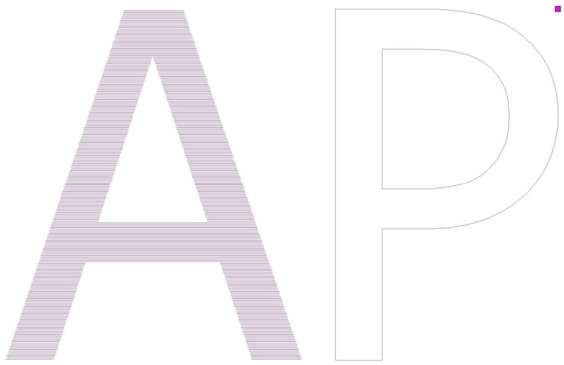

Fig. 5. Sample comparison of two modes of laser scanning provided by CHANXAN CW-1325

Fig. 6 shows that samples were cut by the CO2 laser in a form of a 10 × 10 matrix with each cell having different combination of laser parameters values. The variable parameters were power regulation coefficient k_P for columns and scanning speed v for rows. Values of former varied from 10% to 100% with step being 10%, while values of latter varied from 10 mm/s to 100 mm/s with step being 10 mm/s.

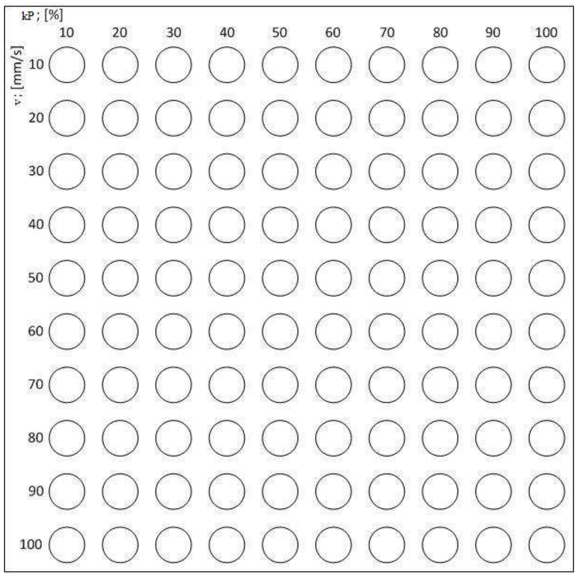

Fig. 6. Matrix of 100 cells with different combinations of values of laser parameters

Thickness of CLT panel was selected so that during experiments the material is not cut through and the depth of cut d can be measured for all combinations of values of laser parameters used during experiment.

Cross-sections of CLT panels were studied to determine the depth *d* of laser cuts as it is shown in Fig. 7.

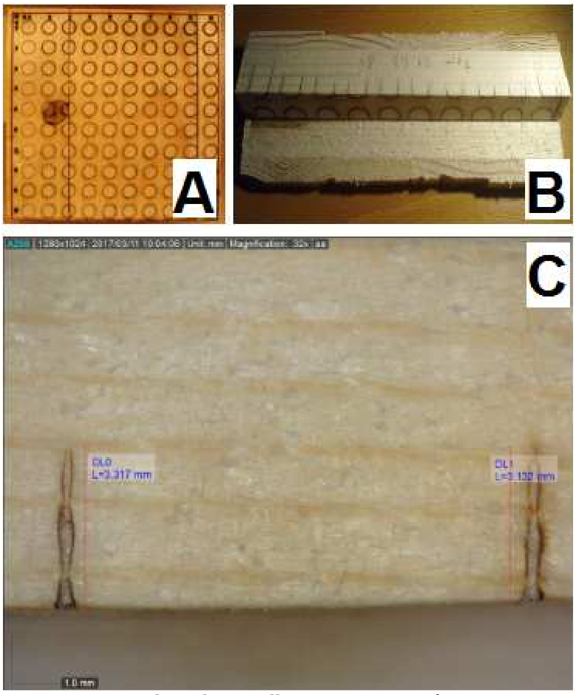

Fig. 7. A – sample with cut cells, B – overview of cross-section of CLT panel, C - cuts measurements under microscope

Samples were cut in such a way as to obtain 4 measurements for one cut (Fig. 8).

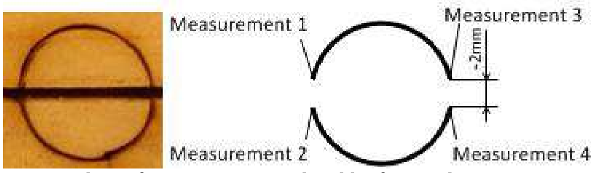

Fig. 8. Place of measurements and width of a circular saw cut

In total from 800 measurements, but 109 were excluded due to errors (wrongly entered parameters, cuts located in lamella gluing place).

C. Additional equipment

For cut depth measurements multi-purpose zoom microscope Dino-Lite Edge AM7115MZT (Fig. 9) was used, technical specifications of which are shown in Table II.

Table II.
Dino-Lite Edge AM7115MZT technical specifications

Resolution	5M pixels (2592x1944)
Magnification	20x~220x
Lighting	8 white LEDs
Unit Dimension	10.5cm (H) x 3.2cm (D)

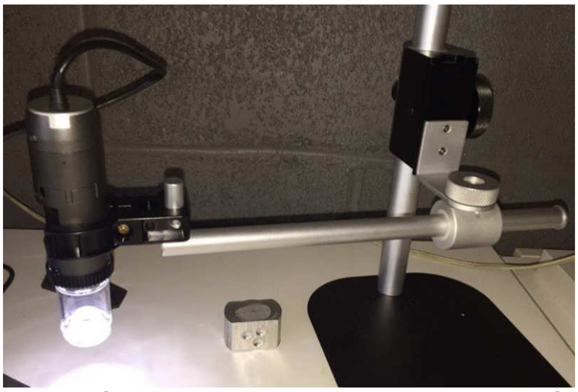

Fig. 9. Multi-purpose zoom microscope Dino-Lite Edge AM7115MZT

Power measurement sensor OPHIR F150A-BB-26 used during measurements of laser power is shown in Fig. 10. Its specifications are summed up in Table III.

Table III.
Power measurement sensor OPHIR F150A-BB-26 specifications

Absorber Type	Broadband
Spectral Range [μm]	0.19 - 20
Aperture diameter [mm]	26
Power Range [W]	0,05 - 150
Power Noise Level [mW]	3
Max Average Power Density [kW/cm^2]	12
Max Energy Desnity [J/cm^2]	10
Power Accuracy [+/-%]	3
Cooling	fan

Fig. 10. Power measurement sensor OPHIR F150A-BB-26

III. RESULTS AND DISCUSSION

In this work a power measurement of a CO2 laser was carried out. This way values of power regulation coefficient k_P were mapped to measured laser power *P*. The measured data was studied and plotted in form of a graph shown in Fig. 11.

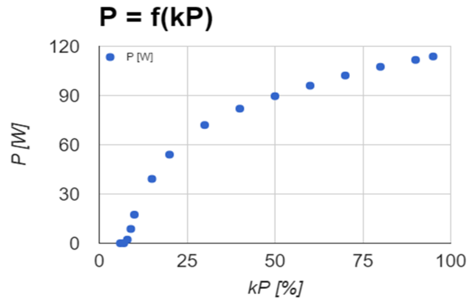

Fig. 11. Mapping of values of power regulation coefficient k_P to laser power P

During preliminary examination of experimental data, it was determined that there exists an alternative way of approaching measurements. Two main laser parameters used during experiments were laser power P and scanning speed v, but from these two parameters an additional parameter can be derived called linear energy density L. Basically, it describes how much energy per unit length material receives from laser beam. To calculate the linear energy density L formula (1) is used.

$$L = \frac{P}{v} \left[\frac{J}{mm}\right] \tag{1}$$

In Fig. 12 one can see, that for specific laser power P there is a certain relationship between cut depth d and scanning speed v. Lower values of scanning speed v result in higher values of linear energy density L, given laser power P is constant. Thus, higher values of linear energy density L correspond to deeper cuts. Nevertheless, the graph in Fig. 12 is hard to interpret, as relationship can only be observed if laser power P is constant. Here it may be easy to choose a necessary scanning speed v for accomplishing laser cutting of wood with specified thickness d, but to determine the scanning speed v for another laser power P a new similar graph would be required.

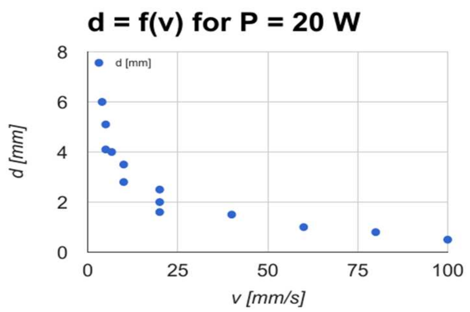

Fig. 12. Mapping of cut depth d value with constant power P and changing scanning speed v

In Fig. 13 one can see the same problem once again. For specific scanning speed v there is a certain relationship between cut depth d and laser power P. Higher values of laser power P result in higher values of linear energy density L, given scanning speed v is constant. As in the previous case, higher values of linear energy density L correspond to deeper cuts. Nevertheless, the graph in Fig. 13 is also hard to interpret, as relationship can only be observed if scanning speed v is constant. Here it may be easy to choose a necessary laser power P for accomplishing laser cutting of wood with specified thickness d, but to determine the laser power P for another scanning speed v a new similar graph would be required.

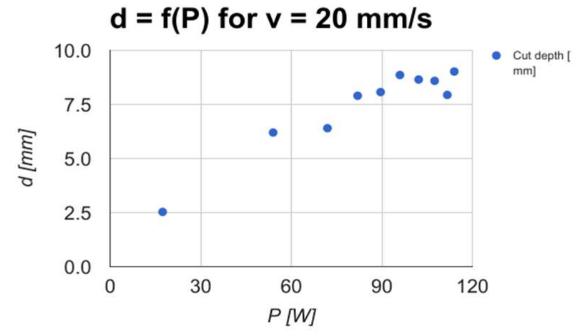

Fig. 13. Mapping of cut depth d value with constant scanning speed v and changing power P

The solution for both problems described above is to plot cut depth d against linear energy density L (Fig. 14). Linear energy density L is calculated using formula (1) and thus is a function of laser power P and scanning speed v both of which do affect cut depth d.

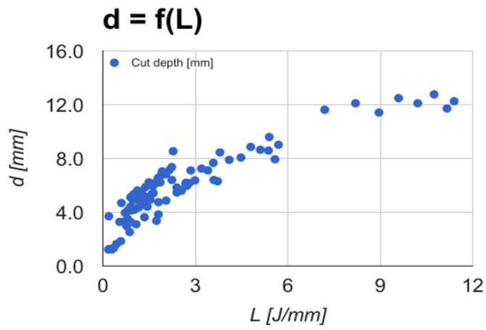

Fig. 14. Mapping the values of cut depth d against linear energy density L

In Fig. 14 one can see a clear relationship between linear energy density L and cut depth d. Interestingly enough, the relationship $d = f(L)$ seems valid no matter what actual values of both laser power P and scanning speed v were used during preliminary experiment. To test it, additional two experiments were carried out, where for specific values of linear energy density L values of laser power P and then values of scanning speed v were varied (Fig. 15).

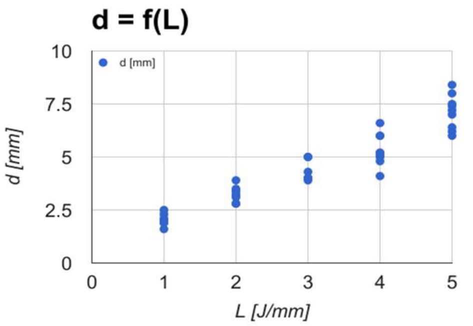

Fig. 15. Cut depth *d* as function of linear energy density *L*

Both Fig. 14 and Fig. 15 display that, given one knows the value of linear energy density *L*, then it is possible to foresee approximate possible cut depth *d* for specific material, i.e., wood. One can also observe that it is possible to make deeper laser cuts, while minimizing value of linear energy density *L*. Based on Fig. 14 it may look that linear energy density *L* is directly proportional to the square of laser cut depth *d*. This means, one requires more and more energy per unit length to cut through thicker plates. This seems true, as the diameter of laser beam spot increases with further distance from lens focus, resulting in weaker intensities.

Interestingly enough, the optimization of values of laser parameters is possible, but further study on effects of linear energy density *L* is required. Basically, there are two ways one could optimize the wood cutting process if only the cut depth *d* is important: either by reducing the amount of time *T* or by reducing the amount of energy *E* required to do the cutting. Ideally, for certain length and depth of cut both time and energy must be minimized (Fig. 16).

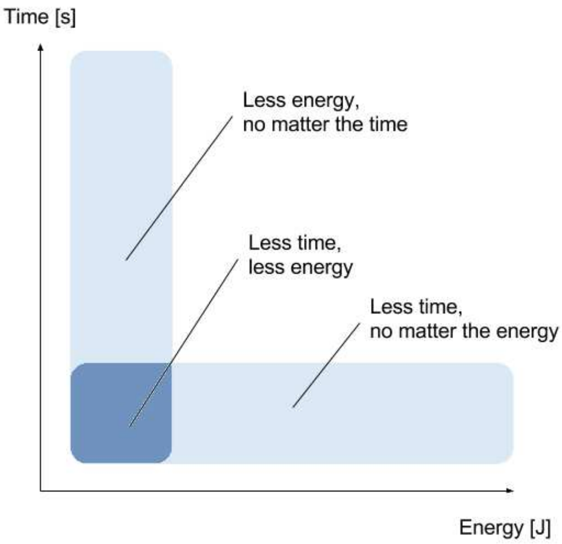

Fig. 16. Optimization of laser cutting by minimization of time and energy necessary for the process

Formula (2) is used to calculate time required to do the laser cutting for certain *length*. One can immediately see that cutting time *T* can only be minimized by increasing the value of scanning speed *v*, given *length* stays constant.

$$T = \frac{length}{v} \; [s] \tag{2}$$

Formula (3) is used to calculate energy required to do the laser cutting for certain *length*. Here one can observe that energy *E* can be minimized by decreasing the value of linear energy density *L*, given *length* stays constant.

$$E = P \cdot T = \frac{P \cdot length}{v} = L \cdot length \; [J] \tag{3}$$

It can be seen in formula (1) that linear energy density *L* itself can be minimized either by decreasing laser power *P* or by increasing scanning speed *v*.

To be able to optimize laser wood cutting process, i.e., find best values for laser power *P* and scanning speed *v*, an algorithm is required. First, linear energy density *L* must be determined for specific cut depth *d*. Next, either lowest possible laser power *P* or highest possible scanning speed *v* must be determined, while keeping linear energy density *L* constant.

Thus, supposing the cut *length* is given and is constant, one must minimize linear energy density *L* in order to minimize total energy *E* required for cutting at the same time maximizing scanning speed *v* in order to minimize total time *T* required for cutting. In the end, necessary minimal laser power *P* required for cutting some plate of given thickness *d* can be calculated as the product of linear energy density *L* and scanning speed *v*.

IV. CONCLUSION

Preliminary investigation resulted in understanding the usefulness of linear energy density *L* parameter and its relationship with cut depth *d*. On the one hand in Fig. 14 one can observe a clear functional relationship between linear energy density *L* and cut depth *d*, while on the other hand in Fig. 15 one can see that for specific value of linear energy density *L* cut depth *d* can deviate from expectations.

For this specific reason additional experiment was carried out for PMMA acrylic material. Here, linear energy density *L*, no matter the actual values of laser power *P* and scanning speed *v*, always corresponded to some specific cut depth *d*. PMMA acrylic compared to wood has more uniform and homogeneous structure, which thus results in more precise results and measurements. After all, the unique structure of wood materials results in less precise cut depths *d* for specific values of linear energy density *L*.

Given, one knows necessary amount of linear energy density *L* necessary for cutting specific cut depth *d*, one has to determine which approach is better to take – cutting fast while wearing and tearing

CO_2 laser tube and mechanical parts of X/Y coordinate system or cutting slow and wasting time.

All in all, there is a clear need for further thorough studies on effects of linear energy density *L* in context of laser cutting process so as to establish a database that will serve as a useful reference for laser cutting of different materials. It is still important to know and understand how specific values of linear energy density *L*, when applied to some material, will behave for extremely low and high values of laser power.

In conclusion, this study is the first one in the coming series of future articles where further features of CO_2 laser will be studied such as "dot mode", i.e., laser radiation can be time controlled and higher values of linear energy density *L* can be set, as wells as raster mode where effects of planar energy density on the depth of engraving are to be studied.

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