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Study of Laser Source Output Characteristics

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Abstract. Laser source is one of the most important components of a laser marking system, others being its scanner and control unit. Laser source is characterized by its output parameters, i.e., factors that define the source and determine its limits. In this study averge laser power, pulse repetition frequency, pulse duration, pulse peak power, and, most importantly, pulse energy are analyzed in order to better determine capabilities of a system.

Keywords: average laser power, laser source, pulse duration, pulse energy, pulse peak power, pulse repetition frequency.

I. INTRODUCTION

In this work the output characteristics of laser sources of Rofin PowerLine F-20 Varia and Chanxan CX-20G are studied. To accomplish that, laser light output was studied for different values of laser source input parameters. Laser light output is characterized by laser source output parameters and adjusted by laser source input parameters. Both Rofin PowerLine F-20 Varia and Chanxan CX-20G (further in text, Rofin and Chanxan) generate laser light in form of a pulse wave that is periodic in both time and space (Fig. 1).

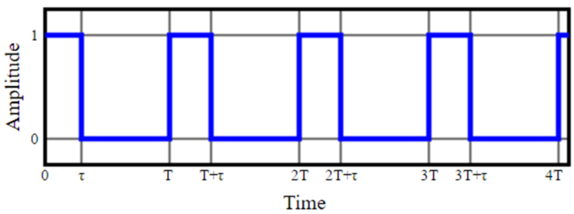

Fig. 1. Schematic representation of pulse wave as a function of time with pulse wave period T and pulse duration τ

Pulsed laser systems do not genereate energy in a form of continuous stream of coherent photons, but instead output photons grouped in form of laser pulses and pulse repetition frequency f relates to the amount of such pulses generated by the laser source in one second [1].

To understand laser source output one needs to study laser light in terms of both laser pulse wave and individual laser pulse. Laser pulse wave can be characterized in terms of both space (and its dimensions) and time. Pulse wave length l (in terms of space) is directly proportional to pulse wave period T (in terms of time), and speed of light c is the constant of this proportionality as shown in formula (1).

$$l = c \cdot T \text{ , [m]} \tag{1}$$

Laser pulse wave period T (temporal pulse spacing, pulse repetition period) represents the amount of time passing between two consecutive laser pulses. Laser pulse wave period T is controlled by pulse repetition frequency f input parameter for both laser marking systems and there is inversely proportional relationship between them as shown in formula (2).

$$f = \frac{1}{T}\text{, [Hz]} \tag{2}$$

Pulse repetition frequency f is measured in inverse seconds (s^{-1}, Hz). Thus, pulse repetition frequency f must be interpreted not as the amount of pulses generated in one second, but instead as the amount of similar events that took place during one second. In case of a pulsed laser, these similar events refer to laser pulses [2].

Laser pulses from the same pulse wave refer to individual pulse that is similar to all other pulses within this pulse wave. This pulse can be described in terms of its energy as having energy E_P equal to that of one laser pulse. Thus, the amount of pulses generated in one second can be described in terms of the total amount of energy generated by a pulsed laser in one second also known as average laser power P as shown in formula (3).

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$$P = E_P \cdot f = \frac{E_P}{T}, \text{ [W]} \tag{3}$$

As shown in formula (3) laser pulse wave period T also represents the amount of time, in which there is energy E_P equal to that of one laser pulse. Because laser pulse wave is periodic, in each such laser pulse wave period T there is energy E_P equal to that of one laser pulse [3].

By itself the laser pulse is a collection of coherent photons of some central frequency. In one particular instant of time, the laser pulse is localized in space [4].

In any straight line forming a plane which is perpendicular to direction of laser pulse propagation and which cross-sects laser pulse (Fig. 2), the distribution of energy (photons) can be characterized by a normal (Gaussian) distribution. Thus, within a laser pulse there is more energy closer to the axis representing direction of laser pulse propagation.

Fig. 2. Normal (Gaussian) distribution of energy within cross-section perpendicular to direction of laser pulse propagation

Laser pulse can be interpreted as a wave packet that has distinct temporal duration τ and thus a directly proportional spatial length ι, with speed of light c being the constant of this proportionality as shown in formula (4).

$$\iota = c \cdot \tau, \text{ [m]} \tag{4}$$

This way pulse energy E_P, which is moving at the speed of light c in certain direction, can cross imaginary plane that is perpendicular to this direction in the amount of time equal to pulse duration τ. In other words, total amount of laser pulse energy E_P that can be delivered in continuous way to a plane perpendicular to direction of its propagation in the amount of time equal to pulse duration τ defines pulse peak power P_P as shown in formula (5).

$$P_P = \frac{E_P}{\tau} = \frac{P}{f \cdot \tau} = \frac{P \cdot T}{\tau}, \text{ [W]} \tag{5}$$

Both average laser power P and pulse peak power P_P characterize the flow of energy in form of laser pulses and/or photons that constitute the laser pulses.

II. METHODOLOGY

A. Laser systems

Laser systems being studied are commonly used for laser marking. They provide several adjustable laser input parameters that can be categorized in three main groups:

- laser source – power regulation coefficient, pulse repetition frequency, pulse duration (only Rofin);
- scanner – scanning speed, line step;
- control unit – repeat count.

Only two parameters are available for adjusting the properties of laser light generated by the laser source of Chanxan – power regulation coefficient k_P and pulse repetition frequency f. Rofin provides additional parameter for adjusting pulse duration τ.

Power regulation coefficient k_P allows laser operator to indirectly set the amount of average power P generated by the laser source. Initially, it was not known how power regulation coefficient k_P affects laser power P, so power measurements for different values of power regulation coefficient k_P were necessary. Before experimental investigation it was assumed that the value of power regulation coefficient k_P is directly proportional to the value of average laser power P on the output and that maximum possible average power $P_{\max}$ = 20 W specified in technical characteristics of both laser systems is a constant of this proportionality as shown in formula (6).

$$P = P_{\max} \cdot k_P, \text{ [W]} \tag{6}$$

Nevertheless, formula (6) does not account for the effect pulse repetition frequency f and pulse duration τ can have on output laser power P. Therefore average laser power P measurements are necessary for different input values of all available laser source input parameters for both laser systems.

The three laser source input parameters under study (power regulation coefficient k_P, pulse repetition frequency f, and pulse duration τ) should provide enough information for calculating average laser power P, pulse energy E_P, and peak power P_P. When values of all these output parameters are determined, interpretation of laser materials processing results becomes considerably easier. Moreover, if values of these laser source output parameters can be repeated on other laser marking systems, then the result of laser marking (color) can also be repeated under similar ambient conditions and for similar material. In other words, these laser source output parameters form a universal system with the help of which it becomes possible to achieve similar processing results using different marking systems.

B. Additional equipment

For taking measurements three different devices were used:

- Power measurement sensor Ophir F150A-BB-26 and Ophir Nova II laser power meter,
- Multi-purpose zoom microscope Dino-Lite Edge AM7115MZT,
- Angle grinder AEG WS 6-125.

C. Measurements

The problem with the laser source is that one can set the laser power P indirectly by adjusting power regulation coefficient k_P. Eventhough it is stated in technical specification of both systems that laser can generate up to P_{max} = 20 W of laser power, the mapping between values of power regulation coefficient k_P and actual average laser power P is not known and has to be measured using power meter.

Measurements were taken for both systems and for different values of all available laser source input parameters. For Rofin, all three laser source parameters affected the output laser power P, while for Chanxan, only power regulation coefficient k_P had an effect similar to that shown in formula (6) (Fig. 3).

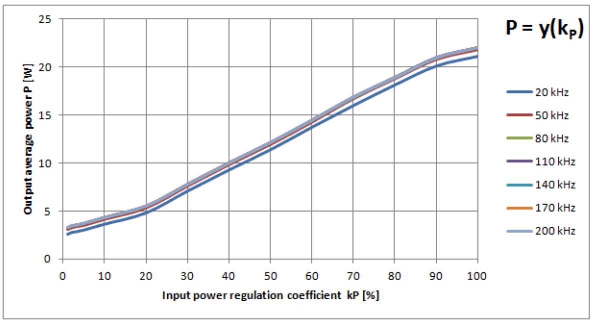

Fig. 3. Chanxan output power P as a function of power regulation coefficient k_P for different values of pulse repetition frequency f

For maximum value of power regulation coefficient k_P, low values of pulse repetition frequency f and each value of pulse duration τ Rofin showed lower average power P output. The value of measured average power P was directly proportional to a value of pulse repetition frequency f up to a certain point f_{limit}, after which average power P reached P_{max} = 20 W and stayed constant for all higher possible values of pulse repetition frequency f (Table I).

While the input and output values of pulse repetition frequency f for Rofin were consistent, on Chanxan additional mapping was necessary. The mapping of input pulse repetition frequency f_i to output pulse repetition frequency f_o was carried out by scanning photosensitive inked paper at high scanning speed v_{max} = 10 m/s. Scanned lines were then analyzed using microscope to measure distance Δy between two consecutive laser pulses as shown in formula (7).

$$\Delta y = \frac{v}{f}, \text{ [m]} \tag{7}$$

Table I

Limit Pulse Repetition Frequency and Maximum Possible Pulse Energy for Every Available Pulse Duration of Rofin

τ, [ns]	f_{limit}, [kHz]	E_{Pmax}, [µJ]
4	500	40
8	200	100
14	125	160
20	111	180
30	83	240
50	63	320
100	40	500
200	20	1000

Because input scanning speed v_i was consistent with output scanning speed v_o, output pulse repetition frequency f_o was determined using formula (7) and mapped as shown in Fig. 4.

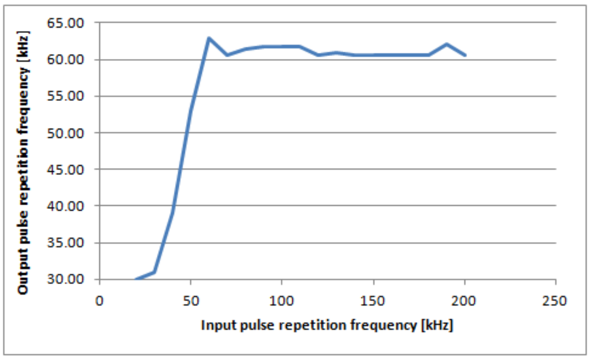

Fig. 4. Mapping of input pulse repetition frequency f_i to output pulse repetition frequency f_o on Chanxan

Based on newly gathered information pulse energy E_P for different possible values of output pulse repetition frequency f_o were determined and graphed in Fig. 5.

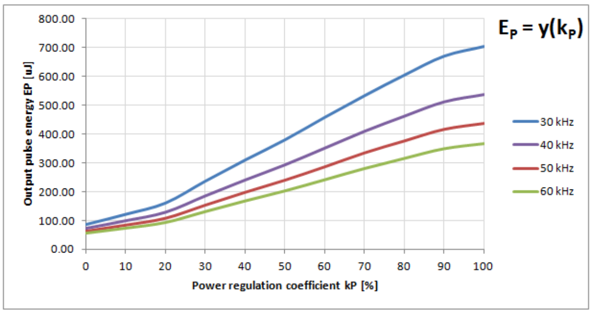

Fig. 5. Chanxan pulse energy E_P as a function of power regulation coefficient k_P for different values of ouptut pulse repetition frequency f_o

To measure pulse duration τ, an angle grinder was used. It allowed to produce scanning speed greater to that of a laser system by a factor of 10. In specifications of angle grinder it was mentioned that it can produce 167 rotations per second or w = 167 Hz. Photosensitive inked paper was cut in form of a circle with diameter d = 170 mm and attached to the angle grinder. Thus, the speed on the edge of a circle could be reached amounting to v_c = 90 m/s as shown in formula (8).

$$v_c = \pi \cdot d \cdot w, \text{ [m/s]} \quad (8)$$

The angular speed w of an angle grinder was tested by lasing a rotating photosensitive inked paper for specific short amount of time t = 5 ms and then measuring the angle θ (specified in turns or full rotations) of a mark left on a paper as shown in formula (9).

$$w = \frac{\theta}{t}, \text{ [Hz]} \quad (9)$$

Angular speed of an angle grinder was consistent, therefore pulse duration τ could be measured. For this, a line of length a = 50 mm was marked at scanning speed v_{max} = 10 m/s and pulse repetition frequency f = 30 kHz on a rotating photosensitive inked paper. Thus, a scanned surface with respect to a laser beam was moving at total speed of v_t = 100 m/s as shown in formula (10) (Fig. 6).

$$v_t = v_c + v_{\max}, \text{ [m/s]} \quad (10)$$

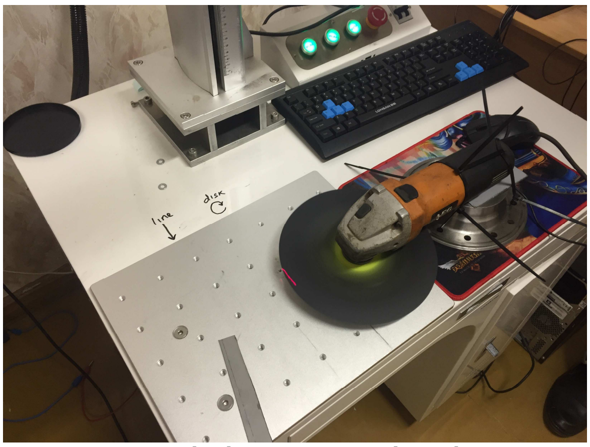

Fig. 6. Measuring pulse duration τ using angle grinder

It was assumed that in certain amount of time τ (pulse duration) the laser beam would scan some certain amount of distance s as shown in formula (11) (Fig. 7).

$$s = v_t \cdot \tau, \text{ [m]} \quad (11)$$

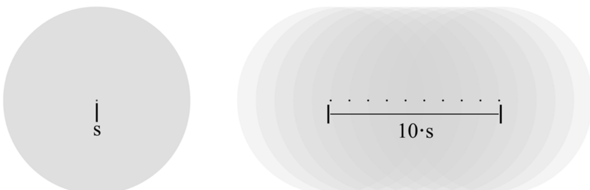

Fig. 7. Distribution of pulse energy on scanned distance s for scanning speed v_{max} = 10 m/s (left) and increased scanning speed v_t = 100 m/s

Because individual laser pulses could leave a mark on photosensitive inked paper, it was possible to measure the scanned distance s using microscope and then calculate the amount of time τ (pulse duration) by using formula (11). Nevertheless, laser pulses left similar round marks for both maximum possible laser scanning speed v_{max} = 10 m/s (Fig. 8) and increased scanning speed v_t = 100 m/s (Fig. 9).

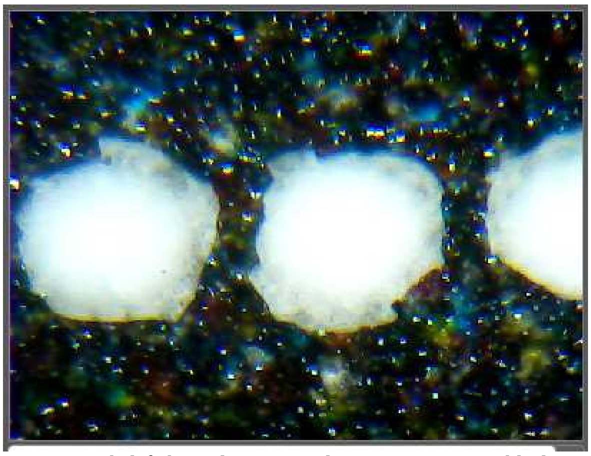

Fig. 8. Mark left by pulses scanned at maximum possible laser scanning speed v_{max} = 10 m/s

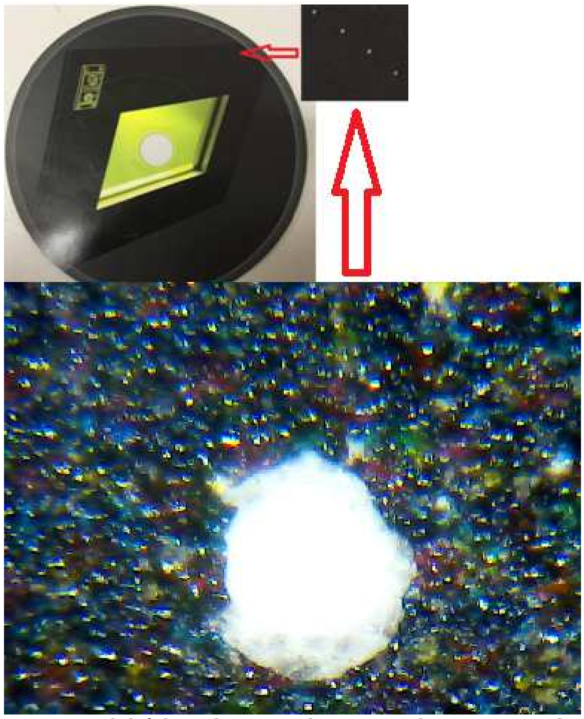

Fig. 9. Mark left by pulse scanned at increased scanning speed v_t = 100 m/s

Thus, energy of a single pulse was distributed over a very small scanned distance s even at increased scanning speed v_t = 100 m/s. Therefore additional mathematical simulation was carried out for distributing energy E_P of a single laser pulse over some scanned distance s (Fig. 10) [5].

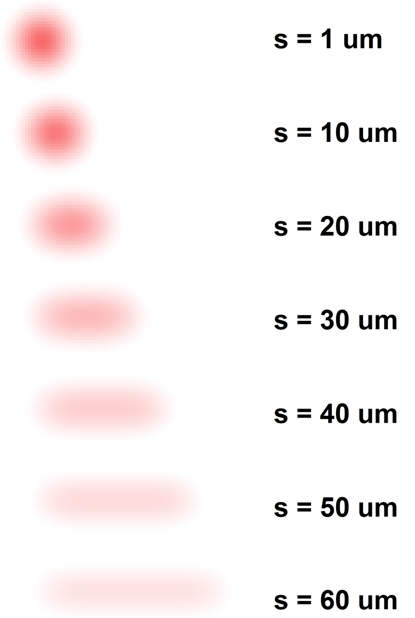

Fig. 10. Simulation of distributing laser pulse energy E_P over some scanned distance *s*

Based on the results of a simulation it can be seen that pulse was scanned over a distance $s \leq 20$ μm, which corresponds to pulse duration $\tau \leq 200$ ns.

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