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LABORATORY EXERCISE TO DETERMINE CONTRAST IN LASER MARKING OF ARTICLES

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Abstract. *The laser marking has been established in recent years as one of the modern innovative methods for marking many industrial products. The report examines a new laboratory exercise for the subject Laser Technology, studied in some technical universities. A new approach is proposed to determine the contrast of the laser marking process. Described is the purpose and the main tasks as well as the new skills and knowledge that students can exercise through this laboratory exercise. Students implement a test matrix consisting of squares of a certain size using the raster marking method. Through the new laboratory exercise, students can explore and analyze the dependencies of the contrast of laser markings on different dimensions influencing the technological process. The capabilities of the new approach allow learners to become more familiar with the factors that influence the modern process of laser marking widely used in modern industry. The results of the experiments the students summarize using a new modern digital approach to analyze the contrast against the background of the marked surface. From the experimental graphical dependencies of the variation of the power and speed contrast, they draw conclusions about the optimal process parameters.*
Keywords: *laser marking, laboratory exercises, software, contrast, power density, frequency, speed words.*

Introduction

In recent decades, various studies have found that training in higher education institutions has been torn off apart from production and labor market

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requirements. At Technical Universities, students do not have enough practical classes to obtain the necessary knowledge and skills to work under real production conditions. This necessitates permanent improvement of the laboratory practices in the technical disciplines according to the constantly changing requirements of the companies in different branches of industry. A new laboratory exercise is offered for Masters students in Physics or Laser Technic and Technologies for the Laser Technology discipline. In the general course of physics they are familiar with the principle of laser action and their device. The technological process of laser marking of different materials is studied.

Laser technology has been undergoing rapid growth in recent years. Optech Consulting (the world's leading laser systems and technology company) is giving an 11-12% annual increase in laser system sales over the period 2008 to 2018. Laser marking is a dynamically developing technology. Progress in electronics and programming over the last decades has greatly increased the possibilities of laser marking compared to traditional marking methods - impact-mechanical, electro-erosion, electrochemical, screen printing, tampon printing, by labels (Pauli, 2010; Pan et al., 1998; Kapur et al., 2013). The emergence of new types of lasers with the necessary characteristics and parameters has contributed to the creation of high-tech marking systems. The positions of laser marking are shown in the studies of (Sobotova & Demec, 2015). It is seen that laser marking is at the forefront with laser cutting compared to other laser technologies (Figure 1).

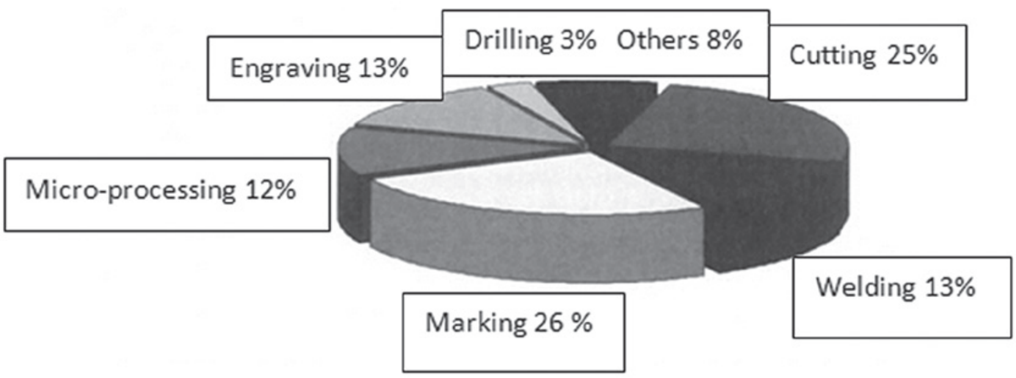

Figure 1 ***Percent distribution of laser technologies*** *(Sobotova et al., 2015)*

Recently, the use of 1D and 2D barcodes has increased considerably. Marking of this type is applied directly to the product. It allows to automate the process of reporting and controlling production, to protect the product from forgery. With laser technology of barcode marking, a high density of information is achieved. In Fig. 2 examples of bar codes are given.

Laser marking is applied to various materials - metals, alloys (including steels), semiconductors, marble, granite, ceramics, plastics, leather, wood, glass, cardboard and others. For each new product, investigating should be done to optimize the laser marking process (Qi et al., 2003; Валиулин et al., 2003; Sobotova et al., 2015; Wang et al., 2015; Ангелов, 2011).

The purpose of the report is to show the possibilities of the new laboratory exercise for optimization of the laser marking process by examining the dependence of the contrast on the power density and speed.

a) *b)*

Figure 2 ***Marking of barcodes: a) 1D; b) 2D.***
(Sources: Pontius, 2012; Adams, 2014)

Exposition

Graduate engineers in the specialty "Laser Technology and Technologies" must have a good theoretical and practical training from the student bench. This laboratory exercise examines a modern technology. It helps students to keep up with industry innovation and appears to be a good asset for their recognition as specialists.

Quality criteria for laser marking

A basic requirement of the obtained laser marking is to be of high quality. Knowing the quality criteria of the marking is of paramount importance for optimizing the laser marking process. In the publications of company Trumpf GmbH Co KG define the following criteria for assessing the quality of the marking:

- Contrast – the resulting mark on the product must be clearly distinguished from the background surface;
- Homogeneity - the marking must be of uniform density along the entire inscription, bar code, matrix code or logo;
- Clarity and sharpness of the image contour - to see even the smallest details of it;

- Wear resistance - the marking must remain unchanged for a long time during operation of the tool or measuring device and be resistant to external influences.

Each of these criteria has its relative weight in optimizing the research process.

Method of experiments

The contrast k^* of the laser marking is a basic criterion for determining its quality. Determined by the ratio of the difference between the brightness of the background J_f and the image J_x onto the background brightness

$$k^* = \frac{J_f - J_x}{J_f}.100\% \ . \qquad (1)$$

The contrast k^* in the laser marking is measured indirectly as follows:

- A test field consisting of squares measuring 5 mm, 15 mm or 20 mm is drawn (Figure 3);
- Marking is applied to the selected sample using a laser marking system;
- A black and white photo of the marked test fields with a digital camera is made.
- The contrast is determined by the reference scale in relative units or percentages. Under the gray tinge of the raster graphics, each image can be represented as a number between 0 (black) and 255 (white). Benchmark number N_f for the surface image around the marked area is determined. For a specific gray scale image by comparison (when merged with a reference image) the corresponding value of N_x is measured. The contrast k_x^* is determined by linear interpolation of the expression

$$k_x^* = \frac{N_f - N_x}{N_f}.100\% . \qquad (2)$$

The contrast k_x^* on an oxidized surface is determined by the expression

$$k_x^* = \frac{N_x - N_f}{N_w - N_f}.100\% , \qquad (3)$$

where N_w is a reference number for the image of the brightest possible marking.

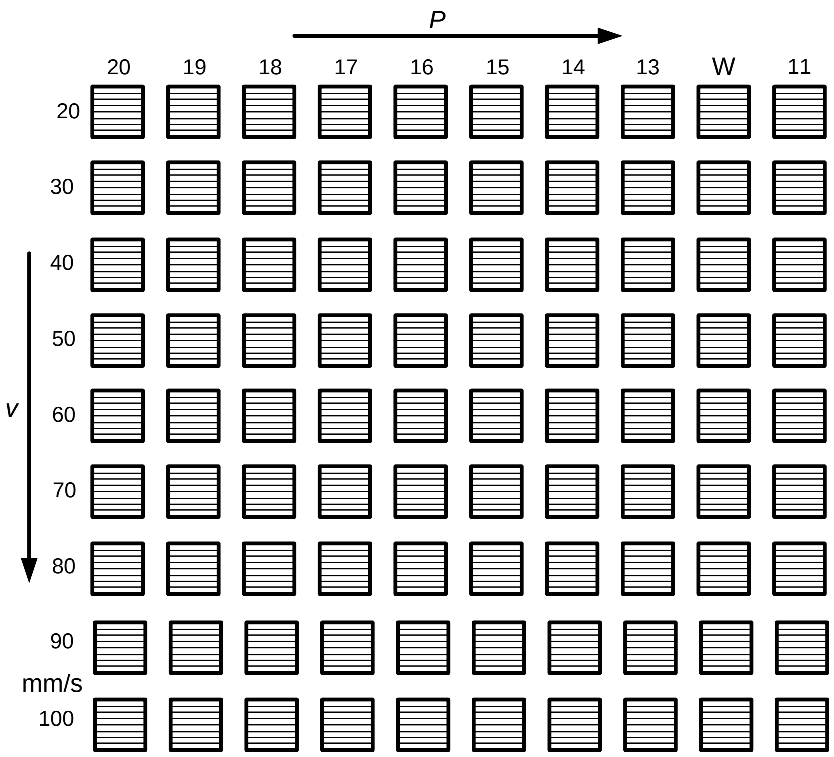

Figure 3 ***Test field for experiments***

Theoretical rationale

Laser marking is a complex technological process. Onto the quality of laser marking influence a number of physical quantities such as power density and speed which are one of the most important.

- Power density of laser radiation

The power density q_S is determined by the formula

$$q_S = \frac{P}{S}, \qquad (4)$$

where S is the surface of the working spot.

Knowing that $S = \frac{\pi d^2}{4}$, it is obtaining

$$q_S = \frac{4P}{\pi d^2}, \qquad (5)$$

where d is the diameter of the working spot.

The upper power limit (and therefore the power density) of each laser source is predetermined, and it is necessary to determine the optimal range of power density variation to achieve good marking quality.

In order to obtain a marking, the laser power density must be sufficient to melt the material in the treatment zone or partial to evaporate. In the studies it is necessary to take into account the fact that with its increase the absorbtion of metals and alloys increases.

- Speed

The speed of marking is one of the most important parameters of the process. It depends on the time of impact on the sample and the energy that is absorbed in the material in the impact area. It is decisive when selecting the marking method.

The speed requirements in the laser marking process are contradictory: on the one hand, the velocity must be high in order to reduce the time taken for the operation to achieve greater efficiency in the manufacture of the article; on the other hand, it must be relatively small so that the necessary amount of energy can be absorbed by the impact in order to reach the required temperature and contrast of the marking. By taking into account the other factors influencing the process, a balance must be found between these contradictory requirements and optimal technological parameters are obtained to achieve the laser marking with the required contrast.

Pre-requisition of the students

Before starting the practical exercise, students should be familiar with the theory of exercise and lasers and laser marking technological systems. They fill in an introductory test located in the MOODLE and Web based system. The teacher assesses the students' tests.

At the beginning of the hour, they answer the following questions:

- ✓ What is the principle of action of laser?
- ✓ What are the main components of each laser?
- ✓ Which types of lasers are suitable for marking (for different materials)?
- ✓ What is the laser marking system?
- ✓ What are the basic parameters of the laser and the laser technological marking system?
- ✓ What are the rules for safe operation of laser technology systems?
- ✓ If both test results are positive, they are allowed to work out the exercise.

Required appliances and materials

The laboratory exercises are selected samples from metals (aluminum, copper, zinc), steels (structural, tool, stainless), colored alloys (bronze, brass), plastics. The teacher selects the specific material for the hours.

The experimenrs are performed with a laser technological system with fiber laser (Figure 4). Its main parameters are given in table. 1. The fiber optic laser is a modern laser operating in the near infrared region. It has extremely high radiation quality and high efficiency. The laser system is with high positioning accuracy and maintains stable performance during operation. It can provide the necessary parameters for realization of the process of laser marking of metals and alloys.

Table 1 ***Basic parameters of the laser technological system for marking***

Parameter	Value
Wavelength λ, nm	1 062
Power P, W	20,0
Frequency ν, kHz	20,0
Pulse duration τ, ns	100
Pulse energy E_p, mJ	1,00
Pulse power P_p, kW	10,0
Beam quality M^2	< 1,1
Positioning accuracy, µm	2,5
Efficiency, %	40

Figure 4 ***Laser technological system for marking with fiber laser***
(Source: www.spilasers.com)

Performance tasks

1. Investigation of the dependence of contrast from the power density in the laser marking of a fiber laser

The exemplary experimental studies refer to C60 carbon steel having a wide application in industry. The power of laser radiation varies in the interval P Є [11.0; 20.0] W with step 1.00 W. The power density q_s is determined by formula (5).

Squares are marked by the raster mode with a certain step that is kept constant. When selecting each square, only the power P is changed and the speed v is kept constant. After performing the experiments and capturing the specimen according to the described methodology, the contrast k^* of the markings for each marked square is determined. Absolute and percentage errors for each measurement are also determined. The results will filled in one a Excel table. Plotting a graph of the contrast k^* from the power density q_s ($k^* = k^*(q_s)$) using the program Excel. The experimental results obtained are analyzed by the student.

2. **Investigation of the dependence of contrast from the speed in the laser marking of a fiber laser**

Experiments are performed on the selected sample. The marking speed changes in the range of v Є [20, 110] mm/s with step 10 mm/s. These refer to two laser power density densities, which are maintained constant at speed change.

After committing the experiments, a photograph of the test field consisting of two columns with 10 squares with a 20 mm side is taken. The contrast of the markings for each squares are determined. The obtained results are applied by the student in the Excel table. Plotting a graph of the experimental dependence of the contrast k^* from the velocity v ($k^* = k^*(v)$), for the two power densities q_s at which the experiment was performed.

Achieved results

In a discussion form with the teacher, the student analyzes: the type of the obtained graphs, the errors and the precision in the determination of the contrast, the intervals for optimal contrast in function of which the two technological parameters studied (power density q_s and velocity v).

The developed laboratory work allows students to achieve:

- Validation of the knowledge of lecture material from the laser marking technology and the factors that influence the process;
- Practical habits and skills for working with a laser marking system;
- Creating a scientific approach to solving research tasks by examining the impact of power density and speed on the contrast of the laser marking;

Conclusion

The proposed lab exercise can be done using a variety of laser marking systems. Thus, by comparing the results obtained, it is possible indirectly to assess the influence of the wavelength of the laser radiation on the absorption capacity and the contrast of the markings.

The acquisition of knowledge for the optimization of the laser marking process of articles from different materials implies the creation of other new laboratory exercises examining the influence of other magnitudes such as frequency and duration of impulses, defocusing, etc. on the contrast of the marking.

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