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Investigation of the Influence of Technological Parameters of Laser Marking on the Degree of Contrast

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Abstract. In modern production, each finished product entering the market is identified by a special marking. Each mark must meet requirements such as good coding, easy to see, easy to read by certain readers, stable over time, etc. In the present casting, laser marking of the C75 steel was carried out with a fiber laser with an average power of $P = 30$ W and a wavelength of $\lambda = 1064$ nm. For semi-contrast marking, marking speeds from 100 mm/s to 700 mm/s, average power from 10 to 30 W, raster pitch from 20 µm to 60 µm, scanning frequency from 20 kHz to 150 kHz were investigated as constant parameters are the pulse duration $\tau = 100$ ns, number of repetitions $N = 1$ and defocus $\Delta f = 0$ mm. The influence of the changing parameters on the contrast was established, and experimental dependences were constructed. The achieved research results show that to obtain a high contrast mark, the average power should be above 20 W, the scanning speed up to 300 mm/s, the scanning frequency up to 50 kHz and the raster pitch up to 40 µm.

Keywords: Laser, Marking, Contrast, Laser Power, step, Marking Speed, Frequency.

I. INTRODUCTION

Laser technologies have developed extremely rapidly in recent years. Lasers are used in medicine, industry, electronics and other fields [1]. One of the directions in which laser technology finds mass application is surface treatment - marking. Each finished product must have a marking applied to it. It must meet the specific needs of the specific production [2]. Contrast, wear resistance and the degree of protection against forgery are part of the mandatory requirements for the marking. Modern systems for easy reading of hatch marks and QR code require the contrast to exceed 15 % [3]-[4]. The contrast of the marking obtained on the article depends on 3 groups of factors related to: the laser source, the technological parameters and the properties of the material [5] - [6]. In the last 10 years, a lot of research has been carried out on marking metal parts using laser systems with wavelengths from 405 nm to 1064 nm. For this purpose, they change the technological parameters of the laser effect in order to obtain a contrast marking or colors marking.

The main part of the so far developed technologies is based on the use of Nd:YAG and Fiber lasers [7] – [8]. Laser sources with a wavelength of $\lambda = 1064$ nm are most often used for laser surface treatment of metals. The low cost of Fiber laser systems, their mass production and the good absorption of this wavelength leads to their wide application in marking metal and other products [7] - [12].

In the last 4 years, the automatic scanning of QR codes has become more and more necessary, which enable more detailed information about the manufacturer of a given product and its application. Laser marking is used to apply information, due to the advantages over traditional technologies such as: non-contact, potential to mark hard-to-reach places, protection of the intellectual property of the manufacturer, etc. It is important for laser marking to meet the necessary contrast and wear-resistance requirements [9].

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The widespread use of laser marking technology on many details needs study into the factors that influence the quality of the marking [10].

The aim of the present study is to determine the optimal parameters of average power (P, W), marking speed (v, mm/s), scanning frequency (v, kHz) and raster pitch (Δx, µm) in laser marking C75 steel to achieve high contrast marking.

II. EXPERIMENTAL STAGING, MATERIAL USED AT THE RESEARCH AND METHODOLOGY

The investigations employed a fiber laser with a power of P = 30 W and a wave length of λ = 1 064 nm. The movement of the laser beam along the surface was carried out using a raster method with Galvo Scanner. C75 carbon steel plates with a thickness of 1 mm are marked. Treated zones are with a form of a square with side 10 mm, and the distance between squares is 2 mm. A series of studies have been done with constant values of the pulse duration τ =100 ns , number of repetitions N = 1 and defocus Δf = 0 mm for each examined area as follows:

First series with change of speed v, mm/s

100	200	*300*	400	500	600	700

at constant power P = 30 W, frequency v = 40 kHz, and step Δx = 30 µm
Dependency graph is being drawn $k^* = k^*(v)$.

Second series with a change of step Δx , µm

20	*30*	*35*	*40*	45	50	60

at constant power P = 30 W, speed v = 300 mm/s, and frequency v = 40 kHz
Dependency graph is being drawn $k^* = k^*(\Delta x)$

Third series with frequency change v , kHz

20	40	60	80	100	120	150

at constant power P = 30 W, speed v = 300 mm/s and step Δx= 30 µm
Dependency graph is being drawn $k^* = k^*(v)$

Fourth series with change of average power P ,

10	12.5	15	17.5	20	25	30

at constant speed v = 300 mm/s, frequency v = 40 kHz and step Δx= 30 µm

Dependency graph is being drawn $k^* = k^*(P)$

The factors that affect the contrast of the marking are shown in Fig. 1.

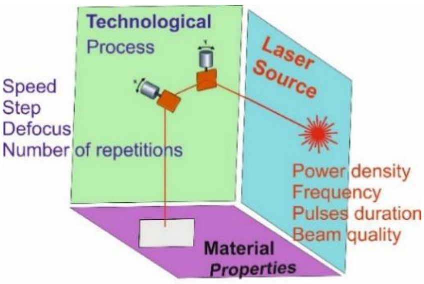

Fig. 1. Major factors affecting marking contrast.

Carbon steel C75 has the following chemical composition for Table 1.

TABLE 1. CHEMICAL COMPOSITION FOR C75

C	Si	Mn	P	S	Cr	Ni
0.70	0.225	0.662	0.009	0.001	0.214	0.071

The substrate has hardness of 442 ÷ 452 HV and roughness R_a from 0.264 ÷ 0.36 µm, R_z from 13.597 ÷ 21.268 µm, R_q from 0.41 ÷ 0.56 µm. Investigations are made into the contrast's dependence on certain processing factors.

The influence of laser mark contrast on average power P; speed v; step Δx; the frequency v is displayed graphically.

The change in the operating mode of the laser system is carried out with the help of the EZCAD software product, which changes within the set limits the studied technological parameters [11].

The parameters of the scanning system and the laser source are presented in Table 2

TABLE 2. PARAMETERS OF THE LASER SYSTEM

Scanner	
Scanning head	GalvoScan
Work area	200 mm x 200 mm
Scan speed	0 ÷ 3000 mm/s
Positioning accuracy	0.02 mm
Focal length	290 mm
Laser	
Laser source	Raycus Fiber
Wavelength	1064 nm
Maximum power	30W
Operating mode	Pulsed mode
Frequency	20 ÷ 200 kHz

The RFL - P 30 Q laser system used in marking the carbon steel samples is shown in Fig. 2.

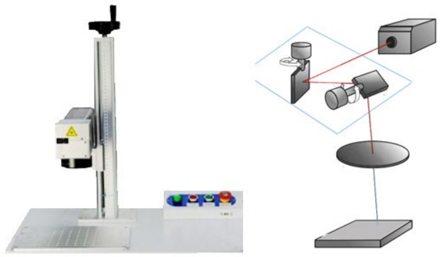

Fig. 2. The RFL - P 30 Q laser system and schematic of the experimental setup.

Analysis of the contrast k^* is performed with Adobe raster image processing software Photoshop CS 6 x64. Colorful pictures on marked samples, were loaded into the program, after which are converted to grayscale. The values of the measurements in the gray scale are taken for each of the processed areas. The range on the values varies of 0 (black) to 255 (white). Each measurement is conducted five times, and the average value is taken as the result.

Grayscale saturation values resulting with Photoshop CS6 2012 are used to determine contrast via the formula:

$$k^* = \frac{N_f - N_x}{N_f}.100,\% \qquad (1)$$

The contrast k^* is determined by linear interpolation, as N_f is the value of the untreated surface, and N_x, of each treated area with different parameters.

III. RESULTS

The results of the first experiment are given in Fig. 3, depict the graphical dependency of contrast on power $k^* = k^*(P)$

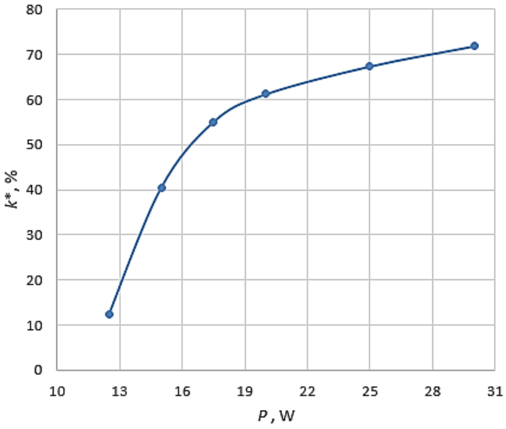

Fig. 3. Graph of the dependence of contrast on power.

The following conclusions can be made from the analysis of the graph:

With increasing power in the range P Є [12, 30] W, the contrast increases exponentially;

The increase in contrast is described by the equation y = -0.002x4 + 0.1971x3 - 7.2887x2 + 120.53x - 691.82;

For powers in the range P Є [12, 17] W the speed of contrast growth as a function of power $\Delta k^*/\Delta P$ is 8.6 % / W

For powers in the range PЄ [17, 30] W the contrast growth rate in $\Delta k^*/\Delta P$ is 1.36 % /W;

The rate of change of contrast in the interval PЄ [12,17] W grows 6 times faster than that in the interval PЄ [17,30] W

The results of the second series are summarized in Fig. 4, graphically representing the dependence

$k^* = k^*(v)$

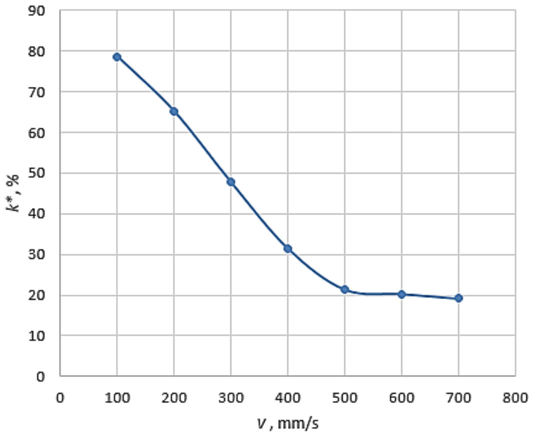

Fig. 4. Graph of the dependence of contrast on speed.

The following conclusions can be made from the analysis of the graph:

When the speed everything increases in the range v Є [100, 500] mm/s , a non-linear decrease in contrast is observed, the rate of decrease $\Delta k^*/\Delta v$ is 0.147 % / mm/s;

For speeds in the range v Є [500, 700] mm/s no change in contrast is observed

For velocities in the interval v Є [400, 700] mm/s is not recommended to be used because the contrast of the marking is close to the minimum value of 15%, for legibility of the marking.

The results of the third series are summarized in Fig. 5, graphically representing the dependences $k^* = k^*(v)$

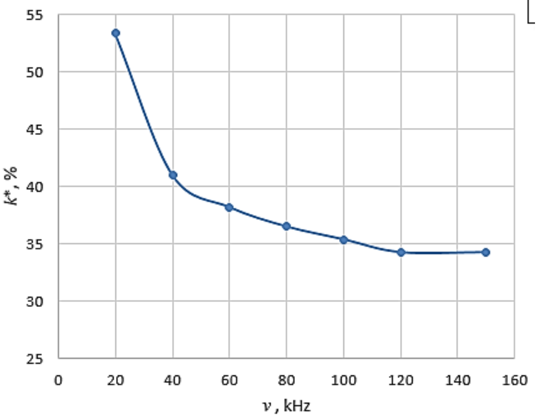

Fig. 5. Graph of the dependence of contrast on frequency.

The following conclusions can be made from the analysis of the graph:

For the investigated frequencies in the range ν Є [40,150] kHz a non-linear decrease in contrast is observed, which is described by the equation y = -8E-09x5 + 4E-06x4 - 0.0007x3 + 0.0643x2 - 2.9088x + 90.875

For frequencies in the range ν Є [20, 40] kHz the rate of contrast decrease as a function of the rate $\Delta k^*/\Delta \nu$ is 0.6 % / kHz.

For the frequency range ν Є [40, 150] the rate of contrast reduction as a function of the rate $\Delta k^*/\Delta \nu$ e 0.087 % / kHz.

For frequencies in the range ν Є [20, 40] kHz the speed of contrast reduction $\Delta k^*/\Delta \nu$ is 7 times larger than in the range ν Є [40, 150] kHz.

The results of the fourth series are shown in Fig. 6, graphically representing the dependence $k^*=k^*(\Delta x)$

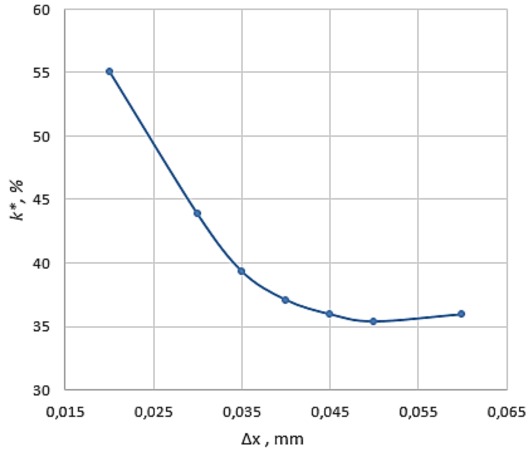

Fig. 6. Graph of the dependence of contrast on step.

The following conclusions can be made from the analysis of the graph:

As the step increases, a decrease in contrast is observed;

For a step Δx = 20 µm, the contrast k* is 16% higher than that for a step Δx = 35 µm;

For a step in the range Δx Є [20, 40] µm the rate of contrast decay as a function of the step $\Delta k^*/\Delta x$ is 0.6 % / µm;

For the range of the step Δx Є [40, 150], the speed of contrast reduction as a function of the step $\Delta k^*/\Delta x$ is 0.087 % / µm;

Contrast in the range Δx Є [20, 40] µm decreased 9 times faster than that in the interval Δx Є [40, 60] µm.

From experimental studies of C75 steel to achieve the required contrast, the following optimal working intervals for marking have been determined:

v Є [200, 400] mm/s
R Є [14,21] W
Δx Є [20, 35] µm
ν Є [20, 40] kHz

The largest change in contrast is observed in the speed changes in the range v Є [100, 500] mm/s , with the contrast varying in the range k^* Є [20, 80]%.

IV. CONCLUSION

In the present study, the following results were achieved for laser marking of C75S steel:

- The influence of the speed on the contrast of the marking was evaluated;
- The influence of the step on the contrast of the marking was evaluated;
- The influence of the power of the laser radiation on the contrast of the marking was evaluated;
- The influence of frequency on marking contrast was evaluated
- Optimization of the researched process was achieved with determination of working intervals of the technological parameters.

Future research is planned to investigate the effect of repetition number and defocus on marking contrast.

V. ACKNOWLEDGMENT

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