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STUDY OF THE INFLUENCE OF DEFOCUSED LASER MARKING PROCESS BY MELTING ON SAMPLES OF STEEL

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Abstract: The studies relate to the process of laser marking by melting on the samples of structural steel. The zone of Raleigh for fiber laser was determined. The theoretical dependences of the diameter of the working spot from defocusing and diameter of the radiation falling on the lens were received. Experiments were realized with 50G structural steel. The dependence of contrast of marking from defocusing for two power densities was determined. Working intervals were determined for studied magnitudes for visual perception of the marking.

Keywords: laser marking, structural steel, fiber laser, contrast, defocusing, working intervals.

1. INTRODUCTION

Lasers are successfully used in industrial technologies, including for marking the products. Specific properties of laser radiation contribute to their widespread use for practical purposes, such as high coherence, monochromaticity, an opportunity to achieve greater energy density (power density respectively) in the working area [1,2]. Laser sources emit radiation with wavelengths over a wide spectral range - ultraviolet, visible and infrared range in continuous and pulsed mode.

Laser sources with different technological parameters for marking are produced globally, but only few of them are used for products of structural steels. In recent years, the market offers the following laser sources suitable for the realization of the studied process: Nd: YAG laser with lamp pumping; Nd: YAG laser with diode pumping; fiber laser; disk laser; CuB Laser; excimer lasers. For each type of products and type of laser a research must be carried out to optimize the process and find the working intervals for the technological parameters. Defocusing is one of the basic technological parameters affecting the quality of marking [3,4].

2. PRESENTATION

The purpose of the paper was to study the influence of defocusing the process of laser marking of articles by melting of structural steel with fiber laser and obtaining working intervals of defocusing.

When exposed to the laser radiation three cases of focusing on the sample are possible - inside the sample (Figure 1a), on the surface of the sample (Figure 1b) and above the sample (Figure 1c). In the second case the work is done in focus and in the other two cases in defocusing mode Δf. When the focus is above the sample surface, defocusing Δf takes positive values, and when it is below the surface of the sample - negative values.

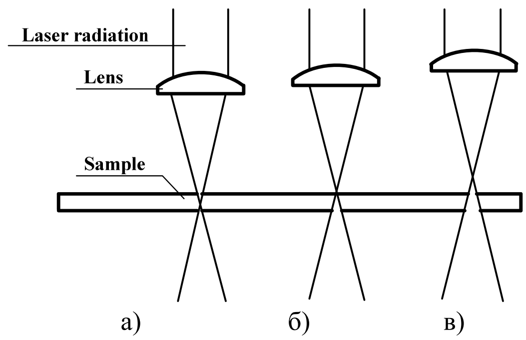

Figure 1. Location of the focus to sample surface: a) inside the sample ($\Delta f < 0$); b) surface of the sample ($\Delta f = 0$); c) above the sample ($\Delta f > 0$).

Influence of defocusing Δf on power density q_S

A. In defocusing smaller than the length of Rayleigh

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When working with defocusing the quality of the resulting marking depends on the length of Raleigh z_R (Figure 2). It is a characteristic of each type of laser. It is defined by the expression

$$z_R = \frac{\pi r_0^2}{\lambda} \quad (1)$$

where λ is the wavelength of the laser, r_0 is the minimum radius of the working spot.

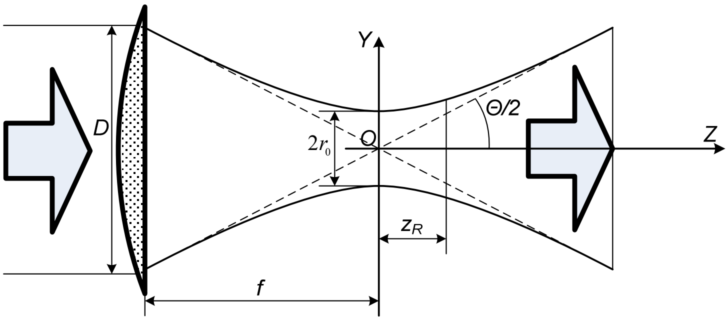

Figure 2. Characteristics of laser radiation length of Raleigh and minimum radius of the working spot

When the condition $\Delta f < z_R$ applies, the diameter of spot does not almost change and therefore power density of laser radiation reduces very little in comparison with that in focus.

B. In defocusing greater than the length of Rayleigh

When the condition $\Delta f < z_R$ is realized, power density of laser radiation reduces very quickly compared to the mode of work in focus. The diameter d of the working spot at defocusing Δf, greater than the length of Raleigh z_R, is given by the formula (Figure 3)

$$d = \frac{D(z' + \Delta f)}{f + z'}, \quad (2)$$

where D is the diameter of the laser beam, falling on the lens, f - focal length of the lens and parameter z' from similarity of triangles (Figure 3) is determined by the expression

$$z' = \frac{d_f f}{D - d_f}, \quad (3)$$

where d_f is the diameter of the spot work in focus.

When $\Delta f > z_R$ it follows from formula (2) that with increasing defocusing Δf increases the diameter d of the working spot , so that the dependency is linear. Power density q_S of laser radiation is inversely proportional to the diameter d of the working spot of the second degree.

$$q_S = \frac{4P}{\pi d^2} \quad (4)$$

where P is the power of laser radiation.

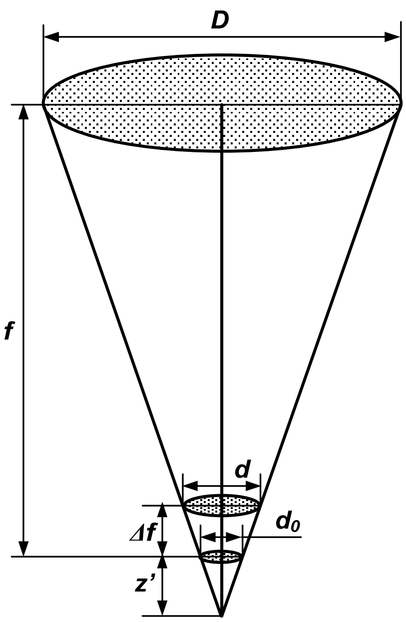

Figure 3. Scheme of the methodology for determining the dependence on the diameter of the spot of defocusing

It follows that the power density q_S rapidly decreases with increasing defocusing Δf. This leads to the exit of the technological mode of marking and inability to obtain a marking with requisite contrast.

50 G steel is widely used in industry. It is used for making friction discs, shafts, gears, spline shafts, connecting rods, electrical rollers, sleeve bearings, cranks, spindles, wheels flywheels, crankshafts of diesel and gas engines and other parts, which pose requirements in terms of high strength and wear resistance. Its chemical composition is given in Table 1 and its basic thermo-physical characteristics are presented in Table 2 [6,7].

Table 1. Chemical composition of the structural alloy steel 50G

Chemical element	C	Cr	Mn	Ni
Content, %	0,48 ÷ 0,56	< 0,30	0,70 ÷ 1,0	< 0,30
Chemical element	Si	P	S	Cu
Content, %	0,17 ÷ 0,37	< 0,035	< 0,035	< 0,30

Table 2. Some thermo-physical characteristics of structural alloy steel 50G: thermal conductivity k, specific heat capacity c, density ρ u thermal diffusivity a

Magnitude Temperature	k, W/(m.K)	c, J/(kg.K)	ρ, kg/m^3	a, m^2/s
20	43	476	7810	$1,16.10^{-5}$
100	42	487	7785	$1,11.10^{-5}$
200	41	500	7755	$1,06.10^{-5}$
300	38	517	7725	$9,51.10^{-6}$
400	36	533	7695	$8,78.10^{-6}$
500	34	559	7665	$7,94.10^{-6}$
600	31	584	7635	$6,95.10^{-6}$
700	29	609	7605	$6,26.10^{-6}$
800	28	676	7575	$5,47.10^{-6}$

Experiments were made with the laser technological system with fiber laser. It is a modern laser operating in the near infrared region and in pulse mode. Its use for laser marking of metals and alloys is constantly expanding. The basic parameters of laser technological system for marking with this laser are given in Table 3 [5].

Table 3. Parameters of laser technological system for marking with fiber laser

Parameter	Value
Wavelength λ, nm	1064
Power P, W	40
Frequency ν, kHz	250
Pulse duration τ, ns	250
Pulse energy E_p, mJ	0,16 ÷ 2,00
Beam quality M^2	1,05
Positioning accuracy, μm	2,5
Efficiency, %	40

Experimental study of the dependence of contrast of marking from defocusing

A. When the focus is inside the sample

Raster fields are marked on the samples of studied steel, with the dimensions of 10 mm x 10 mm. The parameters which are kept constant throughout the experiments are given in Table 4. Defocusing varies in the interval Δf Є [0; 3,50] mm. The focus is situated inside the samples. Defocusing is given with the absolute value.

Table 4. The parameters, which are kept constant during the experiments

Parameter	Value
Power density q_{S1}, W/m^2 Power density q_{S2}, W/m^2	$1,90.10^{10}$ $1,40.10^{10}$
Speed v, mm/s	50
Frequency ν, kHz	30,0
Pulse duration τ, ns	100
Step Δx, μm	50
Number of repetition, N	1

Figure 4 shows the graphs of the experimental dependence $k^* = k^*(\Delta f)$ for two power densities: $q_{S1} = 1,90.10^{10}$ W/m^2 and $q_{S2} = 1,40.10^{10}$ W/m^2. From their analysis we can make the following conclusions:

− In the interval $0 < \Delta f < 0,30$ mm the contrast of marking did not almost change for either power densities. The result agrees with the theory. It works in the zone of Raleigh and power density of laser radiation reduces very slightly;

− In the interval 0,30 mm < Δf < 3,50 mm the contrast of marking reduced quickly. The rate of change on the contrast of the marking is:
19,1 %/mm for $q_{S1} = 1,90.10^{10}$ W/m^2;
17,8 %/mm for $q_{S2} = 1,40.10^{10}$ W/m^2.

− Working intervals of defocusing for marking with fiber laser in visual perception of the marking are:
Δf Є [0; 1,90] mm for $q_{S1} = 1,90.10^{10}$ W/m^2;
Δf Є [0; 1,20] mm for $q_{S2} = 1,40.10^{10}$ W/m^2.

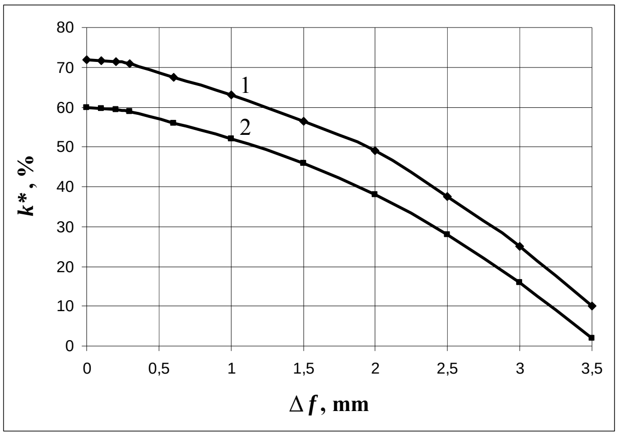

Figure 4. Graphs of dependence k = k*(Δf) for marking with fiber laser on samples of steel 50G of focus inside the sample and for power densities: 1 – q_{S1} = 1,90.10^{10} W/m^2; 2 – q_{S2} = 1,40.10^{10} W/m^2*

B. When the focus is above the sample

Raster fields with dimensions of 10 mm x 10 mm are marked on the samples of studied steel. The parameters which are kept constant throughout the experiments are given in Table 4. Defocusing varies in the interval Δ*f* Є [0; 3,50] mm. The focus is situated above the samples.

Figure 5 shows graphs of the experimental dependence *k** = *k**(Δ*f*) for two power densities: q_{S1} = 1,90.10^{10} W/m^2 and q_{S2} = 1,40.10^{10} W/m^2. From their analysis it follows:

− In the interval 0 < Δ*f* < 0,30 mm the contrast of marking has almost not changed for either power densities. It refers to the zone of Raleigh, where power density of laser radiation reduces very slightly;

− In the interval 0,30 mm < Δ*f* < 3,50 mm the contrast of marking decreases more rapidly than defocusing inside the material. The explanation from the physical point of view is as follows: when the focus is above the surface of the sample, a part of the air is ionized, whereby, due to indirect impact, a plasma cloud is formed. Loss is generated due to the radiation of the cloud. When the focus is inside the material absorption of laser radiation is obtained by free electrons in a thin surface layer. With increasing temperature of the area of impact and increasing of the absorbency of the material, which ultimately further increases the contrast of marking compared to marking with a focus above the surface;

− The rate to decrease the contrast of the marking is:
22,2 %/mm for q_{S1} = 1,90.10^{10} W/m^2;
19,3 %/mm for q_{S2} = 1,40.10^{10} W/m^2;

− Working intervals of defocusing for marking with fiber laser in visual perception of the marking are:
Δ*f* Є [0; 1,75] mm for q_{S1} = 1,90.10^{10} W/m^2;
Δ*f* Є [0; 1,00] mm for q_{S2} = 1,40.10^{10} W/m^2.

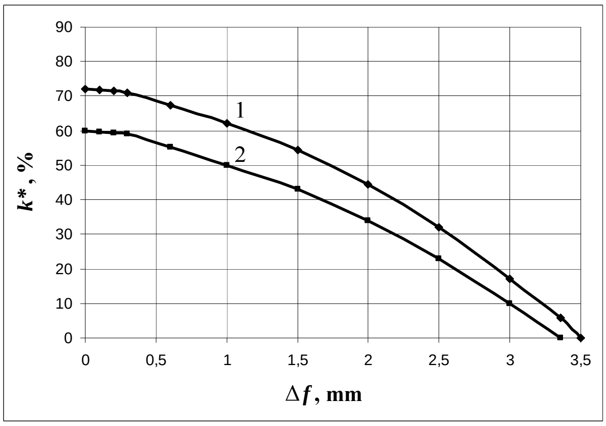

Figure 5. Graphs of dependence k = k*(Δf) for marking with fiber laser on samples of steel 50G of focus above the sample and for power densities: 1 – q_{S1} = 1,90.10^{10} W/m^2; 2 – q_{S2} = 1,40.10^{10} W/m^2*

3. CONCLUSION

Obtained results from experiments and their analysis allow making the following conclusions:

−The work in the mode of defocusing less than the length of Raleigh does not affect the studied process.

−The work in the mode of defocusing greater than the length of Raleigh greatly hampers the realization of the process of laser marking of structural alloy steel 50G;

−The method of marking with a focus inside the product is preferable compared to the method of marking with a focus above the surface of product.

The paper is dedicated to International Year of Light and Light-based Technologies, 2015 (IYL 2015).

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ИЗУЧАВАЊЕ УТИЦАЈА ДЕФОКУСИРАНОГ ЛАСЕРСКОГ ПРОЦЕСА ТОПЉЕЊЕМ НА ОЗНАЧАВАЊЕ УЗОРАКА ЧЕЛИКА

Сажетак: Испитивање се односи на процес ласерског означавања топљењем на узорцима конструкцијског челика. Одређена је Raleigh-ева зона за оптички ласер. Добијене су теоретске зависности пречника радне површине од дефокусирања и пречника зрачења који пада на лећа. Експерименти су рађени на 50 G конструкцијског челика. Одређена је зависност контраста означавања од дефокусирања за двије густине снаге, као и радни интервали за проучаване величине за визуелну перцепцију означавања.

Кључне ријечи: ласерско обиљежавање, конструкцијски челик, оптички ласер, контраст, дефокусирање, радни интервали.