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BOOK 5

"MATHEMATICS, INFORMATICS AND PHYSICS"

VOLUME 10

CONTENTS

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BOOK 5

"MATHEMATICS, INFORMATICS AND PHYSICS"

VOLUME 10

This is the jubilee 10-th volume of book 5 Mathematics, Informatics and Physics. The beginning was in Spring, 2001, when the colleagues of the former section Mathematics and Physics decided to start publishing our own book of the Proceedings of the Union of Scientists – Ruse. The first volume included 24 papers. Through the years there have been authors not only from the Angel Kanchev University of Ruse but as well as from universities of Gabrovo, Varna, Veliko Tarnovo and abroad – Russia, Greece and USA.

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OPTIMIZATION OF THE PROCESS OF LASER MARKING OF METAL PRODUCTS

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Abstract: *The impact of power density and speed on the process of laser marking of aluminum, copper and nickel is studied. Experiments were performed with a fiber laser and a CuBr laser. The dependencies of the contrast of marking on the power density and speed were obtained and analyzed. The optimum intervals of the power density and the speed of laser marking on these metals were determined.*
Keywords: *laser marking, metals, fiber laser, CuBr laser, optimization.*

INTRODUCTION

Laser marking is a complex process which is influenced by a number of factors [1]. Power density of the laser marking and speed are the most important parameters, which help to achieve high contrast and quality marking products. On the speed depends the time of impact upon the sample and the energy, which is absorbed in the material in the zone of impact. It is decisive in the choosing of the method of marking. The power density of the laser radiation should be sufficient in order to induce structural changes in the product, melting of the material in the area of processing and/or partial evaporation. Another fact, which needs to be considered, is that with its rise increases the absorption of the metals.

Because of the critical importance of power density and speed on the laser marking process, each case should be optimized by conducting experiments.

The objective of the study is to obtain optimal intervals of the power density of laser radiation and the laser marking speed on aluminum, copper and nickel products. Experiments were made with a fiber laser and a CuBr laser.

EXPERIMENT

1. Methodology for determination of the contrast of marking

The determination of the contrast in a gray scale is made in the following way:

A program for raster area marking with measures 3 mm x 3 mm, 5 mm x 5 mm or 10 mm x 10 mm, is applied (the necessity is dictated by the requirements for marking of 2D codes and graphics [4, 5, 6]). A black and white photo of the marked test flight is made using a digital camera.

The contrast k^* is determined by an etalon scale in relative units or percentages. By the gray hue any bitmap image can be represented as a number between 0 (black) and 255 (white). A benchmark number N_f for an image on the surface around the zone of marking is defined. In a particular image of a marking, the corresponding value of N_x is measured by comparing the gray scale (the merger with reference image). The contrast k_x^* is determined by a linear interpolation from the expression:

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

The described method allows to be studied the influence onto the contrast k* of a number from technological factors, including power density of laser radiation qS and velocity v of marking.

2. Used materials and lasers

For the experiments are used samples of aluminum, copper and nickel. Their characteristics are shown in Table 1 [2, 7].

Table 1

Metal Magnitude	Aℓ	Cu	Ni
Thermal conductivity *k*, W/(kg.K)	236	401	94
Density *ρ*, kg/m^3	2,70.10^3	8,92.10^3	8,91.10^3
Specific heat capacity c, J/(kg.K)	830	380	440
Thermal diffusivity a, m^2/s	1,05.10^{-4}	1,18.10^{-4}	2,40.10^{-5}
Temperature of melting T_m, K	933,5	1358	1728
Temperature of evaporation T_v, K	2792	2840	3186

The experiments refer to laser fiber SP-40P and laser CuBr. The main technological parameters of laser marking systems for these lasers are given in Table 2 [3, 8].

Table 2

Laser Parameter	CuBr laser	Fiber laser SP-40P
Wavelength *λ*, nm	578	1 062
Power *P*, W	10,0	40,0
Frequency *v*, kHz	19,0	250
Duration of pulses *τ*, ns	30	8 ÷ 250
Pulse energy E_p, mJ	0,51	0,16 ÷ 1,33
Pulse power P_p, kW	17,0	5,32 ÷ 17,8
Quantity of beam M^2	< 1,7	< 1,1
Positioning accuracy, µm	2,5	2,5
Efficiency, %	10	40

3. Realized tasks:

3.1. Investigation of the dependence of the contrast of the marking on the power density of laser radiation.

3.1.1. Results for fiber laser SP-40P

Parameters, which are kept constant during the experiments, are shown in Table 3. Power density q_S of laser radiation is amended in the interval q_S Є [1,03.10^{10}; 2,15.10^{10}] W/m^2 with a step 1,60.10^9 W/m^2.

Table 3

Parameter	Value
Speed *v*, mm/s	60,0
Diameter *d*, µm	40,0
Frequency *ν*, kHz	30
Duration of pulses *τ*, ns	250
Step *Δx*, µm	50
Defocusing *Δf*, mm	0

In Fig. 1 is shown the experimental dependence graphs $k^* = k^*(q_S)$ for samples A ℓ, Cu and Ni. From their analysis can be drawn the following conclusions:

- By increasing the power density of the laser radiation is observed nonlinear increase in the contrast of the three marking materials. The speed of increase of contrast marking v_c is:

Metal	Interval of q_S, W/m^2	v_c, %/(W/m^2)
Nickel	$1{,}03.10^{10} \div 1{,}83.10^{10}$	$3{,}88.10^{-9}$
Aluminum	$1{,}03.10^{10} \div 1{,}83.10^{10}$	$7{,}88.10^{-9}$
Copper	$1{,}35.10^{10} \div 1{,}83.10^{10}$	$10{,}2.10^{-9}$

- In the interval q_S Є [1,83.10^{10}; 2,15.10^{10}] W/m^2 the contrast of the marking increases very slightly for the three materials.
- Optimum intervals of the power density in marking with a fiber laser with speed v = 60 mm/s are:

q_S Є [1,18.10^{10}; 2,15.10^{10}] W/m^2 for Ni;
q_S Є [1,58.10^{10}; 2,15.10^{10}] W/m^2 for Aℓ;
q_S Є [1,76.10^{10}; 2,15.10^{10}] W/m^2 for Cu.

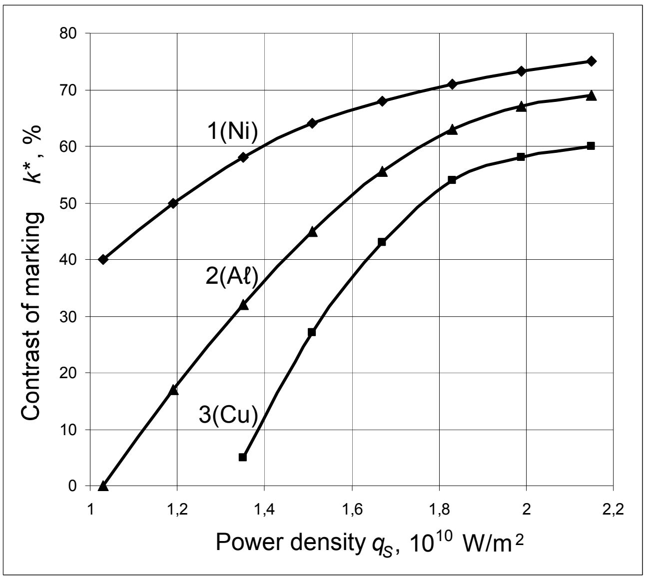

Figure 1. Graphs of the dependence $k^* = k^*(q_S)$ for marking with fiber laser on samples from: Ni - 1; Aℓ - 2; Cu - 3.

3.1.2. Results for CuBr laser

The parameters, which are kept constant during the experiments, are shown in Table. 4. Power density of laser radiation q_S is amended in the interval q_S Є [7,08.10^9; 13,4.10^9] W/m^2 with a step 7,08.10^8 W/m^2.

Table 4

Parameter	Value
Speed v, mm/s	60,0
Diameter d, μm	30,0
Frequency ν, kHz	20
Duration of pulses τ, ns	30
Step Δx, μm	50
Defocusing Δf, mm	0

In Fig. 2 are presented graphs of the experimental dependence $k^* = k^*(q_S)$ for samples of Al, Cu and Ni. From their analysis can be drawn the following conclusions:

- By increasing the power density of the laser radiation is observed nonlinear increase in the contrast of the three marking materials.
- Comparison of the graphs in Fig. 1 and Fig. 2 shows that in order to be obtained the same contrast of marking for a metal is required 30-35% less power density of CuBr laser compared to a laser fiber. This is explained by the greater absorbability of the radiation with a wavelength λ = 578 nm than that of a fiber laser.
- The optimum intervals of the power density when marking with a fiber laser with speed v = 60 mm /s are:

$q_S \in [8,70.10^9; 13,4.10^9]$ W/m^2 for Ni;
$q_S \in [10,1.10^9; 13,4.10^9]$ W/m^2 for Aℓ;
$q_S \in [11,3.10^9; 13,4.10^9]$ W/m^2 for Cu.

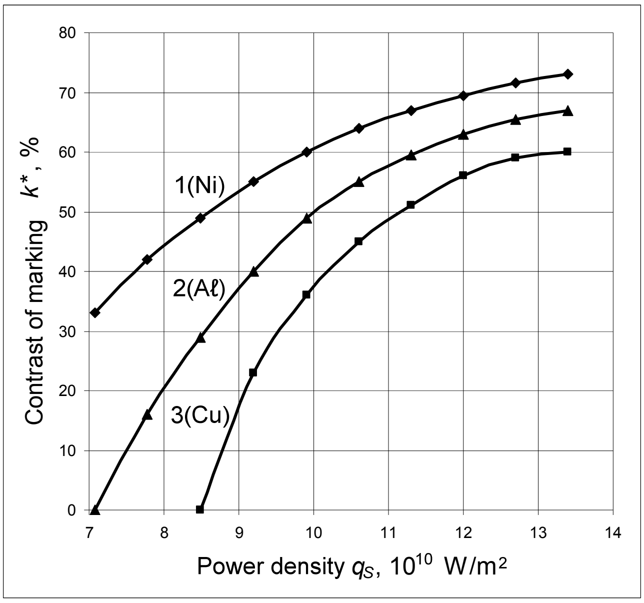

Figure 2. Graphs of the dependence $k^* = k^*(q_S)$ for marking with CuBr laser on samples from: Ni - 1; Aℓ - 2; Cu - 3.

3.2. Investigation of the dependence of the contrast of the marking on the speed.

The parameters of technological system with CuBr laser, which are kept constant during the experiments, are shown in Table 4. Speed marking laser radiation is amended in the interval $v \in [30; 100]$ mm/s with a step of 10 mm/s.

Table 4

Parameter	Value
Power density q_S, W/mm^2	$1,20.10^{10}$
Diameter d, μm	30,0
Frequency ν, kHz	20
Duration of pulses τ, ns	30
Step Δx, μm	50
Defocusing Δf, mm	0

In Fig. 3 are shown the experimental dependence graphs *k** = *k**(*v*) for samples of Al, Cu and Ni. From their analysis can be drawn the following conclusions:

- By increasing the speed of the marking is observed a nonlinear decrease in the contrast of the three studied materials.
- The speed of increase in the contrast of marking in the interval *v* Є [60, 100] mm/s is:

0,79 %/(mm/s) for Ni;
0,82 %/(mm/s) for Aℓ;
0,92 %/(mm/s) for Cu.

- The optimum intervals of speed of marking with CuBr laser for power density q_S = 1,20.10^{10} W/m^2 are:

v Є [30; 90] mm/s for Ni;
v Є [30; 83] mm/s for Aℓ;
v Є [30; 73] mm/s for Cu.

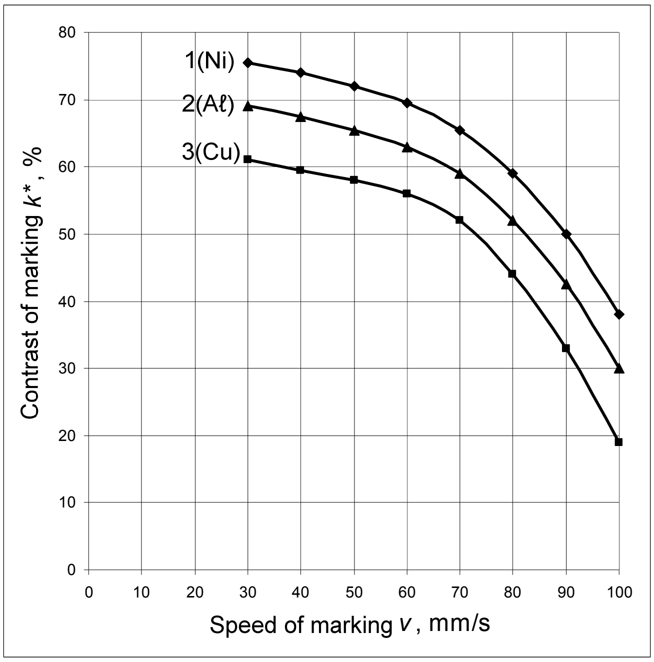

Figure 3. Graphs of the dependence k = k*(v) for marking with CuBr laser on samples from: Ni - 1; Aℓ - 2; Cu - 3.*

CONCLUSION

Results from the experimental studies can be provided in tables with optimum technological process parameters for each case of laser marking. Thus, the work of the laser systems operator is optimized.

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ОПТИМИЗИРАНЕ НА ПРОЦЕСА ЛАЗЕРНО МАРКИРАНЕ НА ИЗДЕЛИЯ ОТ МЕТАЛИ

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Резюме: *Изследвано е влиянието на плътността на мощността и скоростта за лазерно маркиране на алуминий, мед и никел. Експериментите са извършени с файбър лазер и лазер на CuBr. Получени и анализирани са зависимостите на контраста на маркировката от плътността на мощността и от скоростта. Определени са оптимални интервали за плътността на мощността и скоростта за лазерно маркиране тези метали.*

Ключови думи: *лазерно маркиране, метали, файбър лазер, лазер на CuBr, оптимизация.*

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