Optimization of Laser Marking Process with the Help of Stimulation Models

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***Abstract* – In the article we consider the result of several numeral experiments carried out with a program product working under MATLAB for marking of tool steel and electronics elements. We search laser impact of laser CuBr and Nd: YAG laser. We discussed three different simulations with direct attitude toward process of laser marking by modification of pattern surface. The numeral experiments we carried out until the submelting point for examined patterns as we obtained the optimum ranges about basic laser parameters and those for marking technological process.**

***Keywords* – Graphic images, Laser, Temperature field**

I. Introduction

Laser marking takes more and more lasting position in the recent output of electronics and machine-building products since it enables the firms to response to up-to-date requirements for control of quality. The laying of serial numbers, matrix-codes, barcodes, technical parameters, tables and other operative information is the main factor for correct optimization and monitoring of production processes [1]. We have to denote that laser technology for marking equally satisfies requirements for marking of super fragile and miniature elements in electronics as well as of super solid tools and articles of machine-building. Impetuous entering of new technology in the industrial output is due first of all to its special features such as contactless process realization; possibility for variance of marking zone range managing the parameters of lasing, selectivity of impact and simultaneous opportunity to achieve heating, melting or vaporization of material from the processing zone [2].

II. Presentation

The purpose of the report is to present the opportunity for obtaining prognostic working intervals of the basic properties of lasing and technological regimes for laser marking of electronic and machine-building elements.

In our exploration we applied the program product TEMPERATURFELD 3D [3] for simulation of different models and at last we obtained as a final result three dimensional temperature fields in the laser impact zone. In some particular case of laser marking serial number experiments were accomplished to obtain temperature fields at laser marking of pattern, as some of follows parameters are changing [4, 5]: λ - — length of laser wave; q_S - laser power density; τ – length and ν - frequency of repetition of pulses, d - diameter of working spot, v - velocity of marking.

In the simulation optics and thermo-physics material properties values are reading (R – reflection coefficient , δ - depth of penetration of laser beam, k - thermal conductivity, c - specific heat capacity, ρ – density of the material, as well as the way in which they vary when temperature in the zone of activity increases.

The numerical experiments are done with samples of: Si-silicon, Ge-germanium, SiO_2, silicone dioxide, tool steel У10, У11, У12 and У13 and fast-cutting tool steels Р9 and Р6М5 [6]. The sources of heat created as a result of the interaction of lasing and the samples for the first three materials are considered as volumetric and for the steels – as surface [7]. Laser sources with length of laser wave λ = 1064 nm and λ = 511nm are used for the calculations, their basic parameters are specified in table 1.

The following simulations are considered in the research:

- Marking through a surface modification for samples of steel with CuBr laser;
- Marking through a surface modification under impact with Nd: YAG lasers with different duration of impulses for steel samples.
- Marking through a melt of silicone samples with CuBr laser

Table 1. Basic parameters of laser courses

Laser / Parameters	IS 1064	JenLaser MOPA N45	JenLaser MOPA M45	CuBr
Length of wave λ, nm	1064	1064	1064	511
Power P, W	3	20	20	20
Frequency ν, kHz	10	100	100	19
Length of pulse τ, ns	10	100	1000	30
Diameter of working spot d, μm	28	30-80	30-100	30-80

Results and analysis from the research

Subject of research in the first simulation were the temperature profiles in samples of carbon steel under CuBr lasing with density of lasing power q_s ($6{,}00.10^9$ W/m^2 – $1{,}40.10^{10}$ W/m^2) providing maximum temperature on the surface below the melting point (1820 K). This was due to the

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fact that marking through modification of the product's surface through oxidation or structural changes in a very small surface layer is a method often used in practice.

The following conclusions can be drawn from the progress of temperature profiles during the numerical experiments made and shown in fig. 1 and fig. 2:

- Temperature quickly decreases when moving away from the zone of impact in radial direction for distances 200 µm from the centre of the working spot reaching about 3 times values close to environmental temperature;
- When changing the density of power in the range examined, the temperature on the sample's surface varies within limits 850 K – 1780 K.

From the diagram of the temperature field (fig. 1 the power density $q_s = 6.82.10^9$ W/m^2) it is seen , that the surface temperature of the sample is below that of structural changes. In our other real experimental studies with the same power density a pale , low contrast slightly visible line appears (fig.3) . The obtained marking is due to the oxidizing processes on the steel surface. The temperature field on fig.2 indicates the maximum temperatures on the sample surface, exceeding 1003 K, from where structural changes occur (q_s= $9.98.10^9$ W/m^2).

After the comparison of the results from the conducted numeral experiments were made, the intervals for the power density q_s , for which the temperature is in between the allowable for appearing of structural changes in the surface layer were determined as follows: q_s ($8,30.10^9 – 1,15.10^{10}$ W/m^2)

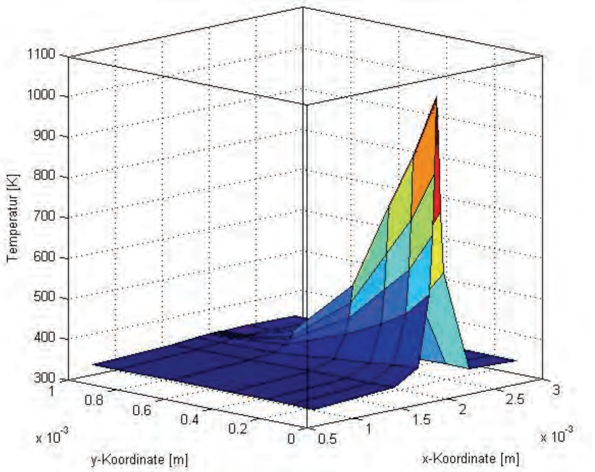


Fig. 1 Graphic of temperature field of instrumental steel У11 for power density $q_S = 6,82.10^9$ W/m^2 with CuBr laser

The critical power density for reaching the melt point in the processing area was determined as q_{Skp}= $1.47.10^{10}$ W/m^2 (Fig 4).

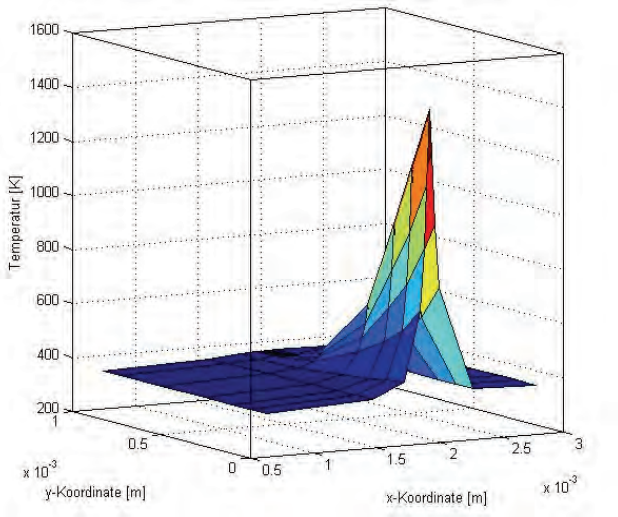


Fig. 2 Graphic of temperature field of instrumental steel У11 for power density $q_S = 9,98.10^9$ W/m^2 with CuBr laser

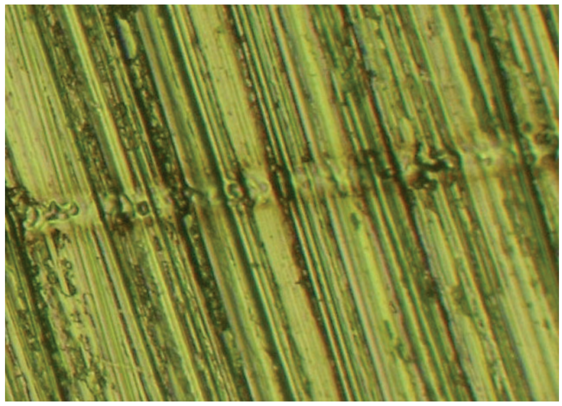
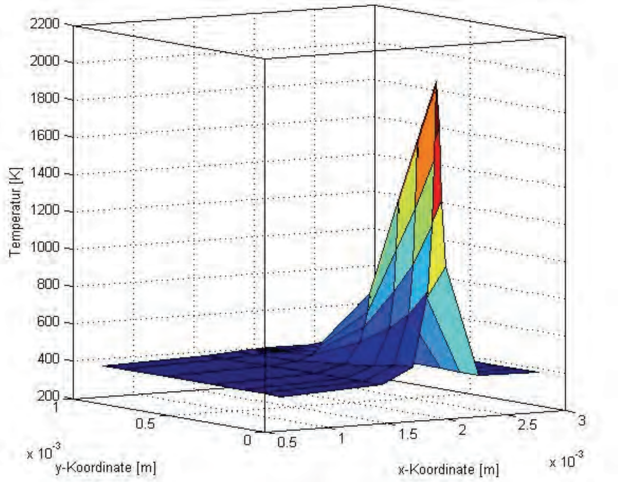


Fig. 3 Laser marking of instrumental steel У11 for power density $q_S = 6,82.10^9$ W/m^2 with CuBr laser



Figr. 4 Graphic of temperature field upon reaching the melting point of instrumental steel У11 ($q_{Skp} = 1,47.10^{10}$ W/m^2), CuBr laser

The investigation of the influence of the pulse length τ on the process of laser-marking was conducted under conditions of other simulation, by using Nd:YAG laser systems in three

different operating modes, respectively (τ = 10 ns; 100 ns; 1000 ns) , see table 1.
On fig. 5, 6 and 7 are presented the temperature fields in the process of laser marking through structural changes of instrument steel У12 , with a velocity v = 100 mm/s with three Nd:YAG lasers.

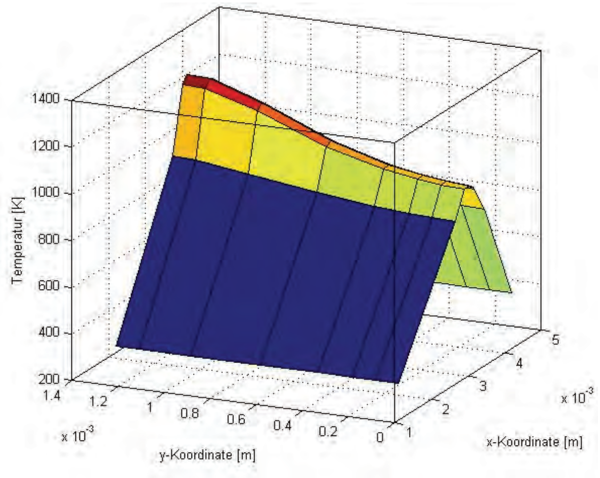


Fig. 5 The temperature field in the process of laser marking through structural changes of instrument steel У12 , with Nd:YAG laser, pulse length τ = 10 ns

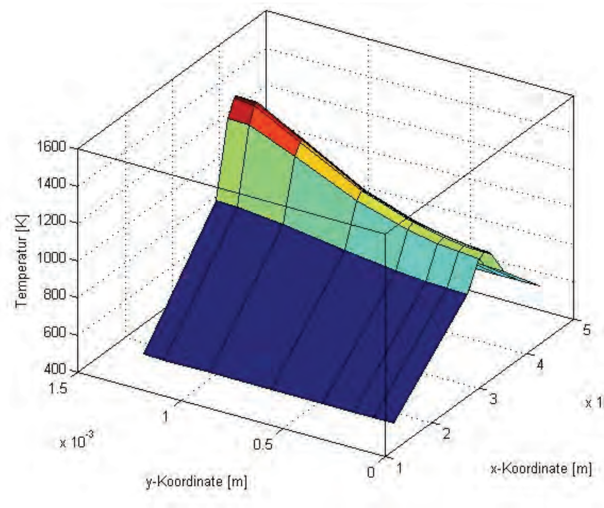


Fig. 6 The temperature field in the process of laser marking through structural changes of instrument steel У12 , with Nd:YAG laser, pulse length τ = 100 ns

From the analysis of the three-dimensional graphical images was determined the following:

- The surface temperature of the samples decreases by 100 K (from 1250 K at 10 ns to 1150 K at 1000 ns) when the pulse length is increased by two orders, nevertheless, that for the three processes is absorbed one and the same quantity of energy in each of the investigated processes;

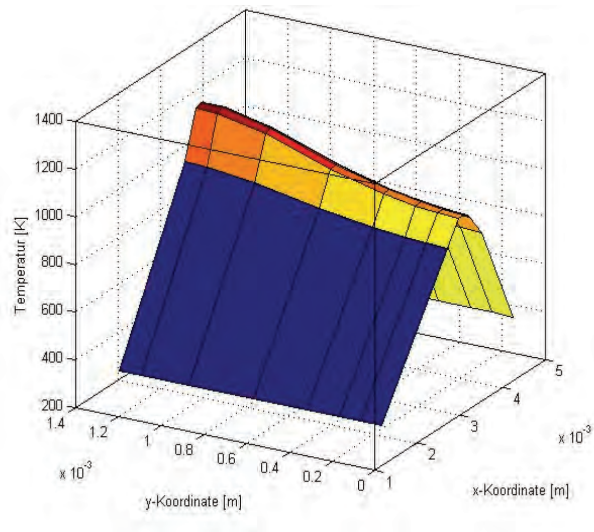


Fig. 7 The temperature field in the process of laser marking through structural changes of instrument steel У12 , with Nd:YAG laser, pulse length τ = 1000 ns

- The heat-impacted area increases nonlinearly with the pulse length increase.

The obtained result has its explanation in the physical model of interaction of the laser radiation with the substance [8] namely: The length of the short pulses is ratable with the time for absorbance of a part from the incident photons from the free electrons and the redistribution of the energy of the electronic gas to the crystal grating . Rapid heating of the impact area appears and accordingly – rapid cooling appear.
The heat transfer through heat conductivity is epsilon squared and practically, the whole absorbed energy remains in this area and its significant temperature increase appears. In the case of bigger pulse length, the heating of the sample surface is slower, and accordingly, slower cooling, compared with the shorter pulses.
The energy transfer through heat conductivity in this case cannot be neglected, the heat impacted area is expanded as part of the absorbed energy is accumulated in it.
This results in obtaining of lower temperatures in the impact area , compared to the case with using of shorter pulses.

In the third simulation the goal is to study the heating of the samples, made of silicon in the process of marking through melting in the impact area, i.e. above the melting temperature. The studies were conducted by using of a Nd:YAG laser at the following initial conditions:
Constant marking velocity v = 50 mm/s ; pulse length τ = 100 ns , spot diameter d = 80 µm.
The changes of the optical and thermal and physical properties with the temperature were also taken in mind in the time of impact, latent heat of melting the material too.
The heat source in the material is considered as volumetric.

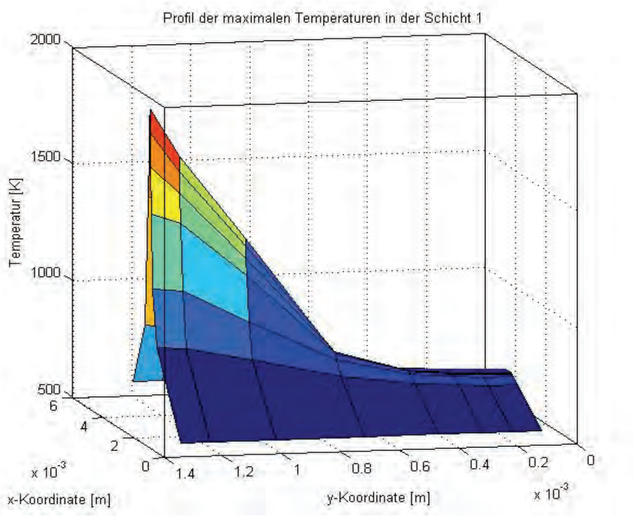


Fig. 8 The temperature field in the process of laser marking of Si with Nd:YAG laser, power density $q_S = 2{,}90.\ 10^9\ W/m^2$.

In the process of investigation the power density is changed in the interval ($2.6\ .10^9$ - $4.3\ .10^9$ W/m^2).

The temperature field for one of these numeric experiments is presented on Fig.3. The power density of the laser radiation for this case is $q_s= 2.9.10^9$ W/m^2

From the analysis of the results from the numeric experiments in this simulation the following conclusions can be made:

- The heat impacted area is comparable with the diameter of the working spot. The temperature gradient in this area is ≈ 10 K / µm;
- The interval for the power density of the laser radiation , where is produced marking through melting on samples, made of silicon should be maintained in the interval $2.7.10^9$ W/m^2 - $3.6.10^9$ W/m^2

III. Conclusion

The use of numeric methods and simulations help for the proper determination of the border zones and operation modes for different laser technological methods for processing of materials. They contribute also for the clarification of complicated issues associated with the thermo-chemical reactions, phase transitions, outbreak of substance in a liquid and evaporated form the zone of the laser impact.

These preliminary experiments result in sparing of funds and time, which is of great importance for the companies, intending to introduce different laser methods in their industrial production process.

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