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OPTIMIZATION OF THE PROCESS OF LASER MARKING OF PRODUCTS MADE OF TOOL STEEL

Introduction. Good quality laser marking is of particular importance to both manufacturers and customers. It is needed by manufacturers so that they could be able to monitor all stages of the production cycle and on the other hand it assures the customer in the parameters featured by the product [1].

Factors which affect the quality of marking are: contrast, homogeneity and clarity of image contour; precision of positioning, wear resistance and absence of product wastes within the impact zone [2].

Laser marking of tool steel products is a complex process and depends on sophisticated relationships between technology parameters which in turn are directly related to the above factors underlying overall quality [3, 4]. Determining individual technology parameters for each particular case of laser marking is in itself a complex optimization task in terms of theory and application. The level of complexity is largely attributed to the fact that there are various methods for marking concerning particular materials and types of surfaces.

Presentation. Contrast is the key factor for determining laser marking quality. Several parameters affect laser marking contrast (fig. 1). According to [5] these can be grouped in the following way:

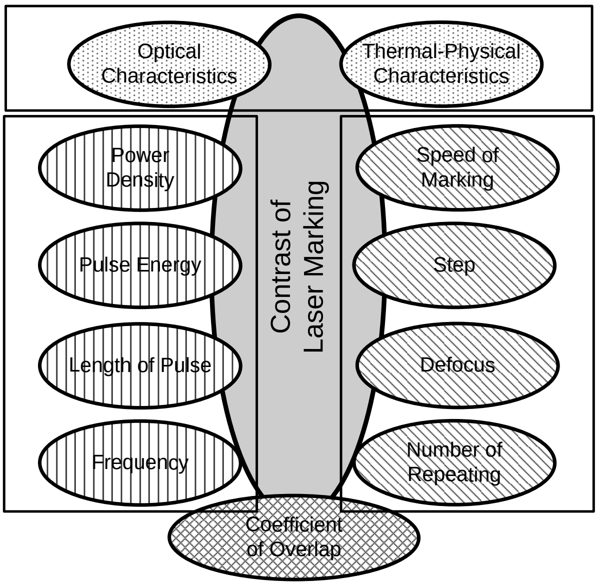

Fig. 1. Key factors affecting laser marking contrast

- Parameters related to laser source – surface density of laser radiation power q_S, pulse energy E_p, frequency of pulse repeating ν, duration of pulses τ;
- Parameters related to material properties – optical and thermal-physical characteristics;
- Parameters related to manufacturing technology process – marking speed v, step Δx, number of repeating N, defocus Δf.

Other parameters include the coefficient of overlapping k_{nn}, the complex parameter which depends both on laser parameters and those of the manufacturing technology process

$k_{nn} = f(v, \nu, d)$, where d is the diameter of the work spot.

Experimental investigations.

This study comprises investigations carried out in the following trends:

- Determining the boundaries between various methods for marking;
- Investigation of the influence of surface density of power q_S and speed of marking v upon contrast k^*.

For determining the boundaries between methods for marking, a series of experimental investigations have been carried out aiming at determining the critical density of the power for melting q_{Sm} and evaporation q_{Sv} intended for samples made of tool steel (carbon steel У7 and rapid steel P6M5) with ground surface. In these experiments we used fiber laser which features a number of advantages [6, 7] as compared to other technology lasers for marking.

Investigation results of q_{Scrm} at speeds for marking within the range of v Є [20, 100] mm/s are shown in fig. 2. Based on the obtained results it is possible to conclude the following:

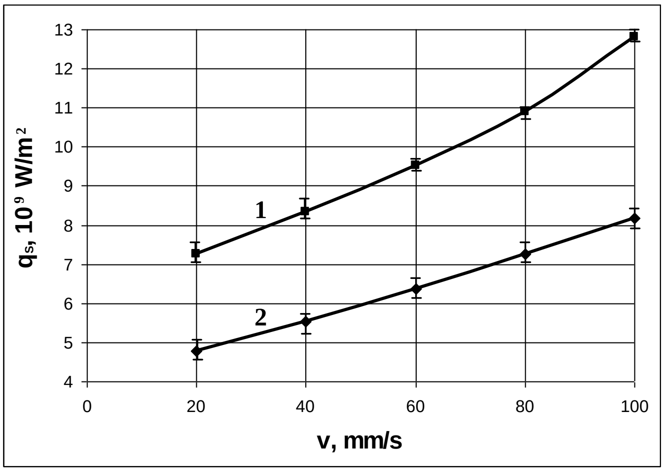

Fig. 2. Dependence of critical density of power for melting q_{Scrm}
on the speed v for fiber laser SP– 40P; investigation samples:
1–carbon tool steel У7; 2 – rapid steel P6M5

- Dependence of $q_{Scrm} = q_{Scrm}(v)$ within the investigated range is almost linear for the tested samples;
- Critical density of power q_{Scrm} for samples of carbon steel У7 during melting is about 1,7 times lower compared to that made of rapid steel tool P6M5. The explanation of this experimental result can be attributed to the presence of some difficult to melt additives in the composition of rapid tool steels – 5,5 ÷ 6,5% W, 1,7 ÷ 2,1% V, 4,8 ÷ 5,3% Mo;
- For the interval of speeds v Є [20, 100] mm/s critical density of the melting power varies within the range q_S Є $[4{,}77.10^9;\ 8{,}19.10^9]$ W/m^2 for steel *У7* and q_S Є $[7{,}27.10^9;\ 12{,}8.10^9]$ W/m^2 for steel P6M5.

A series of experiments have been carried out aiming at investigating technology parameters (surface density of power q_S and speed of marking v) upon contrast k^* of the marking. Well ground samples were prepared from steel У7 which were covered by marked raster zones with dimensions 3x3 mm с 40 W Fiber laser SP-40P. For measuring contrast k^* was used the methodology prescribed by the Bulgarian State Standard 16383:1986.

Contrast k^* is determined in percentage through a reference scale of grey color either in relative units or in percents. A black and white photo is made in the marking zone for the purpose of contrast measuring. By comparing the investigated image with the reference scale a value N_x varying between 0 (black) and 255 (white) is selected. A reference number N_f is set for the background (that is the image on the surface around the marked zone). Contrast k_x^* is defined by way of linear interpolation from the expression

$$k_x^* = \frac{N_f - N_x}{N_f}.100.$$

In visual evaluation of made markings, according to Vasilev [8], a possible good quality criterion demands a contrast of over 50% whereas in using computer aided readers for 2D and bar codes, the contrast should be at least 20% [9, 10].

Investigation results are shown in fig.3 In the series of experiments for five different speeds for treatment, power density of laser radiation varies within the interval q_S Є [0,95.10^{10}; 2,87.10^{10}] W/m^2 by a step of 3,2.10^9 W/m^2.

Graphs' analysis leads to the following conclusions:

- The greater the surface density of laser radiation power q_S the greater the contrast of marking obtained k^* where:

– for marking speed v = 20 mm/s this dependence is almost linear and the speed for contrast intensity of the marking is very low- 1,0.10^{-9} %/(W/m^2). Over the entire investigated range marking by means of evaporation is observed.

– for the interval q_S Є [0,95.10^{10}; 1,40.10^{10}] W/m^2 contrast rises rapidly by speed:

6,5.10^{-9} %/(W/m^2) for speed of marking v = 40 mm/s and v = 60 mm/s;

10,7.10^{-9} %/(W/m^2) for speed of marking v = 80 mm/s и v = 100 mm/s,

– for the interval q_S Є [1,40.10^{10}; 2,87.10^{10}] W/m^2 the contrast grows slowly as the dependence is close to the linear one.

In the first interval marking through melting is obtained whilst in the second one marking is obtained via evaporation.

- The optimum intervals for surface power density q_S at different speeds of marking v are indicated in table.

Table

v, mm/s	q_S, W/m^2
20	0,95.10^{10} ÷ 1,95.10^{10}
40	1,04.10^{10} ÷ 2,07.10^{10}
60	1,17.10^{10} ÷ 2,18.10^{10}
80	1,30.10^{10} ÷ 2,30.10^{10}
100	1,47.10^{10} ÷ 2,40.10^{10}

The lower limit of the obtained optimum intervals corresponds to the requirements for minimum contrast k^* = 50% in perceiving the marking visually. The upper limit is according the requirement for good quality, namely: no presence of additional wastes in the working zone.

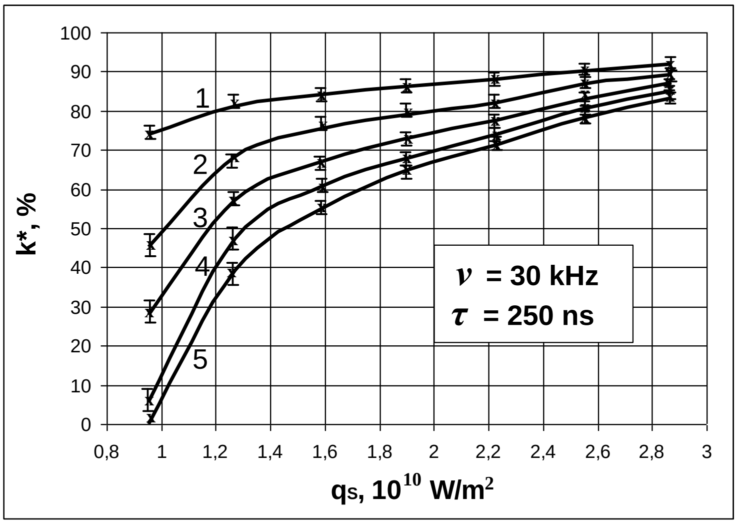

Fig. 3 Graphic diagram of the experimental dependence $k^* = k^*(q_S)$ for steel У7 in marking with fiber laser SP - 40P at speed: 1 - v = 20 mm/s; 2 - v = 40 mm/s; 3 - v = 60 mm/s; 4 - v = 80 mm/s; 5 - v = 100 mm/s.

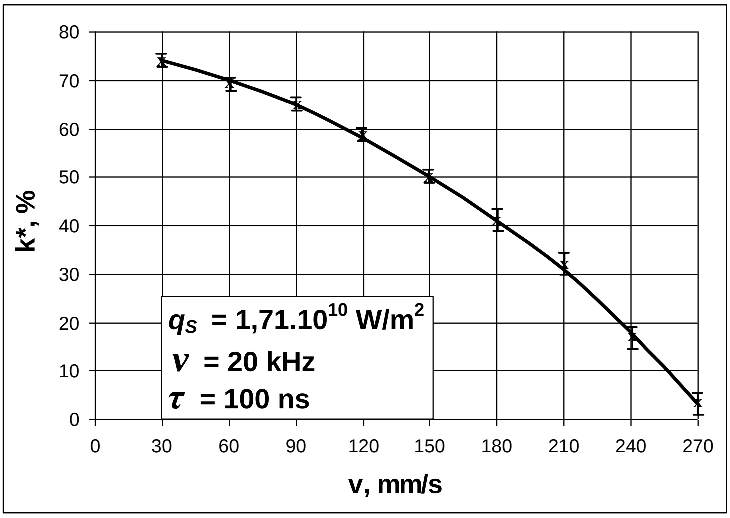

Fig. 4 Graphic diagram of the experimental dependence $k^* = k^*(v)$ for sample made of carbon tool steel У7 in marking with fiber laser UF – 20

Results obtained from the experiments on the influence of speed upon contrast k^* are presented in fig.4. The speed of marking varies within the interval v Є [30, 270] mm/s by step of 30 mm/s.

Drawing upon the results obtained it is possible to make the following conclusions:

- Contrast diminishes by 0,30 %/(mm/s) with the increase of speed;
- The optimum interval for the speed of marking with surface density of laser radiation power $q_S = 1{,}71.10^{10}$ W/m^2 e v Є [30, 150] mm/s in perceiving marking visually.

Conclusion. The results obtained will be a useful aid to the operators of laser technology systems for marking as they contribute to considerable reduction of set up time in real manufacturing settings. These experiments are to be continued with investigation of the influence of different types of surfaces (polished, ground with various stages of roughness, nickel coated or oxidized) on the manufacturing process of marking. The aim is to create a data base of manufacturing technology tables which will serve the needs of real industrial marking during manufacture of products made of tool steels.

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Optimization of the Process of Laser Marking of Products Made of Tool Steel

Special consideration is given to parameters affecting the contrast of laser marking on tool steel products and relevant experimental results are reported related to determining the critical density of laser radiation power in melting and evaporation of steel types У7 and Р6М5. The dependence of contrast from marking speed and power density is also presented.

Key words: laser marking, tool steel, contrast.

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Оптимізація процесу лазерного маркування виробів із інструментальної сталі

Особливу увагу приділено параметрам, що стосуються контрастності лазерного маркування на виробах із інструментальної сталі; надано важливі результати експерименту, які пов'язані з визначенням критичної щільності лазерної потужності в процесі плавки та напилення сталі типів У7 і Р6М5. Розглянуто залежність контрасту від швидкості маркування і щільності потужності.

Ключові слова: лазерне маркування, інструментальна сталь, контраст.

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Оптимизация процесса лазерной маркировки изделий из инструментальной стали

Особое внимание уделено параметрам, затрагивающим контрастность лазерной маркировки на изделиях из инструментальной стали, описываются важные результаты эксперимента связанные с определением критической плотности лазерной мощности излучения в процессе плавки и напыления стали типов У7 и Р6М5. Представлена зависимость контраста от скорости маркировки и плотности мощности.

Ключевые слова: лазерная маркировка, инструментальная сталь, контраст.

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