Influence of Basic Parameters of the Laser Marking Process on Stainless Steel Samples

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Abstract. **The role of basic quantities influencing the process of laser raster marking of AISI 304 stainless steel products using a fiber laser was investigated. Some dependencies were found when changing the contrast of the marking when changing the parameters in wide intervals. As the raster step increases, a non-linear decrease in contrast occurs as the rate of contrast decrease. Regarding the influence of the speed on the contrast, it was found that as the speed increases, the contrast of the marking decreases non-linearly, and as the step increases, the speed of the contrast decrease also increases. Above 20 kHz, the frequency has relatively little influence on the contrast, as with increasing frequency the contrast slowly increases and the dependence is almost linear. The effective energy is strongly influenced by the contrast. At effective energy values below 18 kJ/cm² the contrast of the marking is insufficient for visual perception of a good quality marking, but in the interval from 6 kJ/cm² to 46 kJ/cm² the contrast increases very quickly. At values of the effective energy above 100 kJ/cm², the contrast of the marking hardly changes.**

The obtained results can be used by the operators of laser systems to evaluate the working ranges and quickly determine the boundary areas of the optimal technological parameters when obtaining a good contrast in the laser marking of stainless steels with a fiber laser.

Keywords: contrast, fiber laser, frequency, laser marking, raster step, speed, stainless steel, working intervals.

I. INTRODUCTION

Laser marking is a technology for creating permanent alphanumeric characters, advertising logos, QR and UDI codes directly on finished products. Laser marking provides a unique combination of speed, high positioning accuracy and flexibility [1]. Lasers can mark a wide variety of materials, they are reliable, durable and relatively economical. The technology is used in all industrial sectors and can eliminate secondary processes such as the use of consumables and secondary processing and features easy system maintenance [2]-[6]. Stainless steel materials are used in the food industry as well as in the automotive, electronics, medical and engineering industries [7]-[9]. In article [10], the influence of operating parameters on contrast, roughness and oxide layer during laser marking of AISI 304 stainless steel is investigated. In article [11], the authors use a nanosecond pulsed laser to induce surface staining of stainless steel, one of the main parameters that they change in the experiments is the focal length, the repetition rate and the scanning speed. In article [12], the authors present experiments to produce colors on stainless steel. They research how, through changes in the thickness of the resulting layers, a variety of colors can be obtained. In article [13], the authors experimented with two types of continuous mode (CW) lasers with different wavelengths 1064 nm and 532 nm to produce contrast marking on aluminum. The conclusions they draw are that the treated areas in argon and in air do not show a difference in the color of the mark, but the experiments reveal a difference in the amount of material removed, with the ablation being greater with the laser operating in the visible spectrum. In article [14], the authors modified

the surface of duplex stainless steel by laser processing. Experiments are done on the influence of the raster step on the roughness. In the article [15], the author gives an overview of some laser technological processes such as laser surface alloying, coating application, laser hardening.

The scientific research in this paper aim to investigate the influence of some basic parameters such as effective energy, raster step, speed, and frequency on contrast in laser marking with a nanosecond fiber laser.

II. MATERIAL AND LASER SYSTEM

A. Preparation of the material

AISI 304 / EN 1.4301 stainless steel with the composition shown in Table 1 was used in this study, the samples were 0.8 mm thick. The material is austenitic steel with high corrosion resistance. This grade of stainless steel has very low magnetization and is suitable for welding, forging and cold forming.

TABLE 1 CHEMICAL COMPOSITION OF THE STUDIED AISI 304 STAINLESS STEEL

Element	C	Cr	Mn	S
Content, %	≤ 0.07	17.5 ÷ 19.5	≤ 2.00	≤ 0.03
Element	Si	Ni	N	P
Content, %	≤ 1.00	8.0 ÷ 10.5	≤ 0.10	≤ 0.045

B. Laser system

Fig. 1. Laser technological marking system.

The research was done with a laser technology system with a fiber laser. It is a pulsed laser that operates in the near infrared region ($\lambda = 1.064$ μm). The fiber laser is characterized by high quality beam, high efficiency and low maintenance costs. The system has by high precision and good positioning accuracy. A general view of the laser technology system with which the experiments were performed is given in Fig. 1. Its main parameters are presented in Table 2.

TABLE 2 CHARACTERISTICS OF THE LASER SYSTEM

Parameters	Values
Wavelength λ, μm	1.064
Power P, W	20
Frequency v, kHz	1 ÷ 200
Speed v, mm/s	1 ÷ 2000
Focal length f, mm	254
Spot diameter d, μm	60
Positioning accuracy, μm	2.5
Efficiency, %	40

III. METHODOLOGY OF EXPERIMENTS

Samples of cold-rolled steel sheet AISI 304 with a thickness of 0.8 mm were used for the experiment.

- Samples were prepared in a rectangular shape with dimensions of 100 mm × 65 mm (see Fig. 2);
- Before starting the laser marking process, the polymer film protecting the surface was removed from the samples, after which the surface was washed with isopropyl alcohol;
- The working field consists of 5 rows of 8 square modules with dimensions of 10 mm × 10 mm and a distance of 2 mm between them. An example change of the working parameters is shown in Fig. 2;
- The matrices are captured with a scanning device, the contrast $k*$ is determined from the grayscale images by the formula (1)

$$k_x* = \frac{N_f - N_x}{N_f} \cdot 100\% \quad , \quad (1)$$

where N_f is the darkening value reported for the background and N_x is the darkening value reported for the particular square.
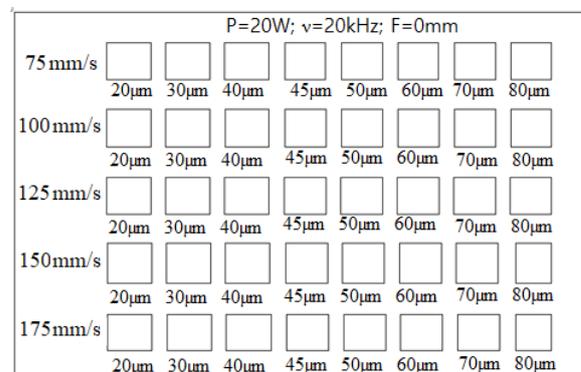
Fig. 2. Sample matrix on which the experiments are performed.

IV. RESULTS

The pre-prepared samples were raster marked with the fiber laser. Contrast was then determined using the gray scale for each square. The following tasks were performed:

A. Investigation of the influence of raster pitch on contrast

The raster step was varied in the interval $\Delta x \in [20, 80]$ µm. The quantities that remained constant are given in Table 3. The resulting images for a speed of 75 mm/s are presented in Fig. 3. From the obtained data, a graphics of the dependence of the contrast k^* on the raster step Δx for three marking speeds 75 mm/s, 125 mm/s and 125 mm/s were drawn (see Fig. 4). The following conclusions may be made:

- As the raster step increases, contrast decreases;
- In the interval of the raster step $\Delta x \in [20, 80]$ µm, the contrast changes in the interval $k^* \in [68, 48]$ % for a speed of 75 mm/s;
- In the interval of the raster step $\Delta x \in [20, 80]$ µm, the contrast changes in the interval $k^* \in [64, 42]$ % for a speed of 125 mm/s;
- In the studied interval of the raster step, the contrast changes in the interval $k^* \in [60, 36]$ % for a speed of 175 mm/s.
- The rate of contrast change is
  0.33 %/µm for speed 75 mm/s;
  0.37 %/µm for speed 125 mm/s;
  0.40 %/µm for speed 175 mm/s.
- The working intervals of the raster step are
  $\Delta x \in [20, 76]$ µm for speed 75 mm/s;
  $\Delta x \in [20, 63]$ µm for speed 125 mm/s;
  $\Delta x \in [20, 47]$ µm for speed 175 mm/s.

TABLE 3 QUANTITIES THAT DO NOT CHANGE DURING THE EXPERIMENTS

Parameters	Values
Power P, W	20
Frequency v, kHz	20
Speed v_1, mm/s	75
v_2, mm/s	125
v_3, mm/s	175
Spot diameter d, µm	60
Number of repetition N	1
Defocus Δf, mm	0
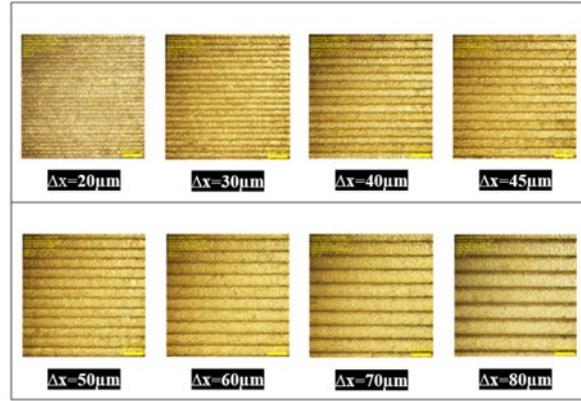
Fig. 3. Obtained images from laser raster marking for a speed of 75 mm/s and a raster step of 20 µm to 80 µm.
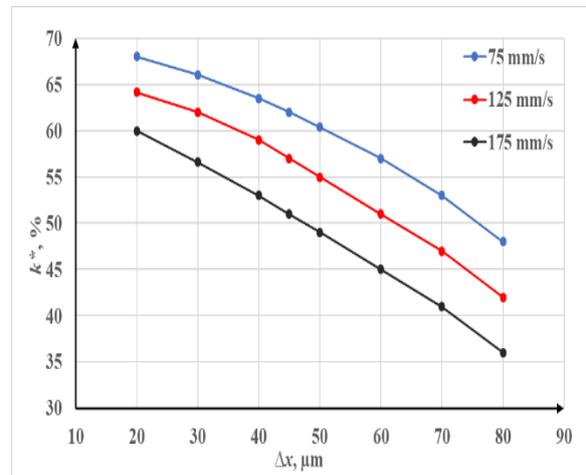
Fig. 4. Experimental graphics of the dependence of the contrast on the raster step.

B. Investigation of the influence of speed on contrast

The marking speed was varied in the interval $v \in [25, 175]$ mm/s. The quantities that remained constant are given in Table 4. From the obtained data, a graphics of the dependence of the contrast k^* on the speed v for three raster steps 20 µm, 45 µm and 80 µm were drawn (see Fig. 5). The following conclusions may be made:

- As the speed increases, contrast decreases;
- In the interval of the speed $v \in [25, 175]$ mm/s, the contrast changes in the interval $k^* \in [72, 60]$ % for a raster step of 20 µm;
- In the interval of the speed $v \in [25, 175]$ mm/s, the contrast changes in the interval $k^* \in [66, 51]$ % for a raster step of 45 µm;
- In the studied interval of the speed, the contrast changes in the interval $k^* \in [52, 36]$ % for a raster step of 80 µm.
- The rate of contrast change is
  0.08 %/(mm/s) for raster step 20 µm;
  0.10 %/(mm/s) for raster step 45 µm;
  0.11 %/(mm/s) for raster step 80 µm.

- The working intervals of the speed are
  $v \in$ [25, 175] mm/s for raster step 20 µm;
  $v \in$ [25, 175] mm/s for raster step 45 µm;
  $v \in$ [25, 50] mm/s for raster step 80 µm.

TABLE 4 QUANTITIES THAT DO NOT CHANGE DURING THE EXPERIMENTS

Parameters	Values
Power P, W	20
Frequency v, kHz	20
Raster step Δx_1, µm	20
Δx_2, µm	45
Δx_3, µm	80
Spot diameter d, µm	60
Number of repetition N	1
Defocus Δf, mm	0
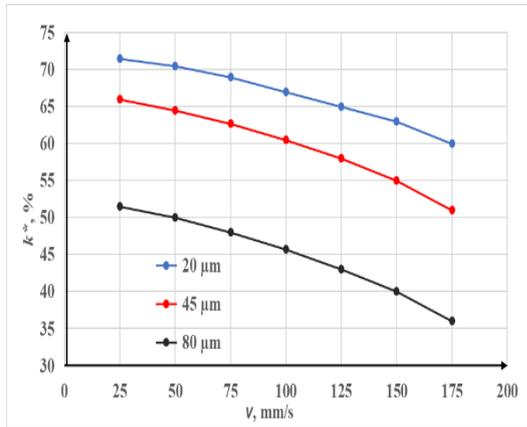
Fig. 5. Experimental graphics of the dependence of the contrast on the speed.

C. Investigation of the influence of frequency on contrast

The frequency was varied in the interval $v \in$ [20, 200] kHz. The quantities that remained constant are given in Table 5. From the obtained data, a graphics of the dependence of the contrast $k*$ on the frequency v for three marking speeds 75 mm/s, 125 mm/s and 175 mm/s were drawn (see Fig. 6). The following conclusions may be made:

- As the frequency increases, contrast also decreases;
- In the interval of the frequency $v \in$ [20, 200] kHz, the contrast changes in the interval $k* \in$ [68, 79] % for a speed of 75 mm/s;
- In the interval of the frequency $v \in$ [20, 200] kHz, the contrast changes in the interval $k* \in$ [64, 72] % for a speed of 125 mm/s;
- In the studied interval of the speed, the contrast changes in the interval $k* \in$ [60, 65] % for a speed of 175 mm/s.
- The rate of contrast change is
  0.061 %/(kHz) for speed 75 mm/s;
  0.044 %/(kHz) for speed of 125 mm/s;
  0.029 %/(kHz) for speed of 175 mm/s.

TABLE 5 QUANTITIES THAT DO NOT CHANGE DURING THE EXPERIMENTS

Parameters	Values
Power P, W	20
Speed v_1, mm/s	75
v_2, mm/s	125
v_3, mm/s	175
Spot diameter d, µm	60
Number of repetition N	1
Defocus Δf, mm	0
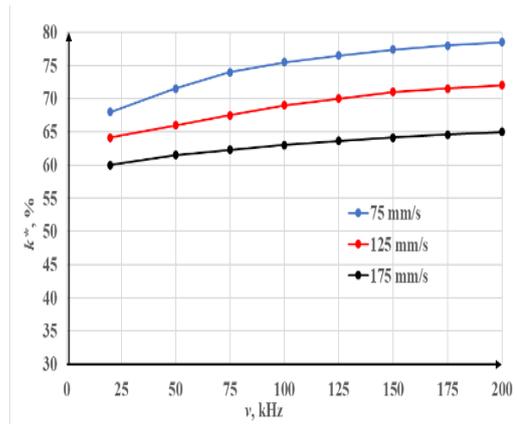
Fig. 6. Experimental graphics of the dependence of the contrast on the frequency.

D. Investigation of the influence of effective energy on contrast

The effective energy was varied in the interval $E_{eff} \in$ [6, 388] kJ/cm². From the obtained data, a graphic of the dependence of the contrast $k*$ on the effective energy E_{eff} was drawn (see Fig. 7). The following conclusions may be made:

- As the effective energy increases, contrast increases;
- In the interval of the speed $E_{eff} \in$ [6, 388] kJ/cm², the contrast changes in the interval $k* \in$ [6, 70] %;
- The rate of contrast change is
  1.45 %/(kJ/cm²) for interval $E_{eff} \in$ [6, 46] kJ/cm²;
  0.017 %/(kJ/cm²) for interval $E_{eff} \in$ [46, 388] kJ/cm²;
- The working interval of the speed is
  $E_{eff} \in$ [18, 388] kJ/cm².
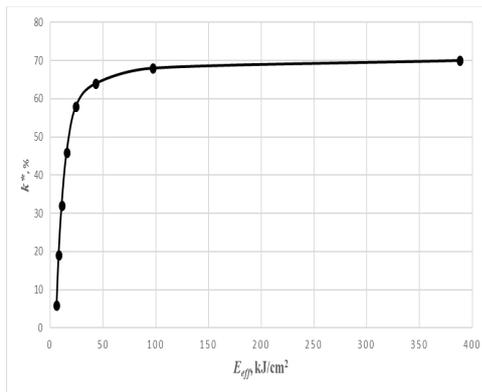
Fig. 7. Experimental graphics of the dependence of the contrast on the effective energy.

V. CONCLUSION

Fiber laser marking experiments were performed on stainless steel samples. The influence of raster pitch, frequency, speed, and effective energy on labeling contrast was investigated. The obtained graphic dependencies of:

the contrast $k*$ from the speed v of processing;

the contrast $k*$ from the frequency v of pulses;

the contrast $k*$ from the raster step Δx;

the contrast $k*$ from the effective energy E_{eff},

can be used to create technological tables defining the optimal limits of the investigated process for marking contrast satisfying the user's requirements.

The obtained results are useful for operators of laser technology systems working in production.

VI. ACNOWLEDGEMENT

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