

Assessment of laser marking contrast with profilometer

A V Sivenkov, O S Chirkova, D A Konchus, E I Priahin

St. Petersburg Mining University, 21st Line of Vasilyevsky Island, St Petersburg, 199106, Russian Federation

E-mail: sivenkov@mail.ru

Annotation. A simple and affordable method for estimating the contrast of laser marking with QR-code using a profilometer is proposed. The method is based on the existence of a direct relationship between the contrast and the roughness of the code - the contrast increases with an increase in the surface roughness. The use of a profilometer makes it possible to determine the features of a complex relief that negatively affect the contrast of the code.

1. Introduction

The laser industry is one of the few competitive areas in Russia. To maintain the leading positions in this field, it is necessary to improve not only the well-studied processes of cutting, welding and melting [1], but also the development and spread of the laser marking process. Clear laser marking promotes confident readability of QR-code on products. For a clear laser marking, a contrast evaluation of the code elements is necessary.

The physical and mechanical properties can be changed by modifying the surface layer [2, 3]. The contrast of the marking depends on the reflection of light by the surface. The laser radiation effect on the metal surface is accompanied by the formation of a wave-like relief on the crater surface. The change in the initial roughness of the surface affects the reflectivity.

An important modern research topic is the assurance of the quality of metal products [4-7]. Recently, lasers are widely used for marking, which make it possible to obtain a high quality of the output beam, which is practically independent of the radiation power. Therefore, this equipment is relevant for use in the study of laser marking. The contrast of the marked image is determined mainly by a spectrophotometer [8] or by means of a graphical editor Adobe Photoshop [9]. To improve the quality of marking, a comprehensive study of the entire code surface is necessary, and not of its individual sections, as in the works [10, 11]. It should be noted that the authors [10] observed the creation of a characteristic surface structure by laser radiation and assumed its influence on contrast, but the authors did not follow this question further. The methodology based on this phenomenon is reflected in this work, which makes it a source of new information on the topic.

2. Materials and methods

The code is marked with laser marking on cold rolled steel 12X18H10 sheets with a thickness of 1.5 mm and surface roughness $Ra = 0.11$ mkm. Steel 12X18H10 is austenitic grade steel, corrosion-resistant, heat-resistant (up to 800 °C) and heat-resistant (up to 600 °C). The chemical composition of steel 12X18H10 in accordance with GOST 5632-72 is given in Table 1. It is used for the manufacture of welded equipment (parts of exhaust systems, pipes).

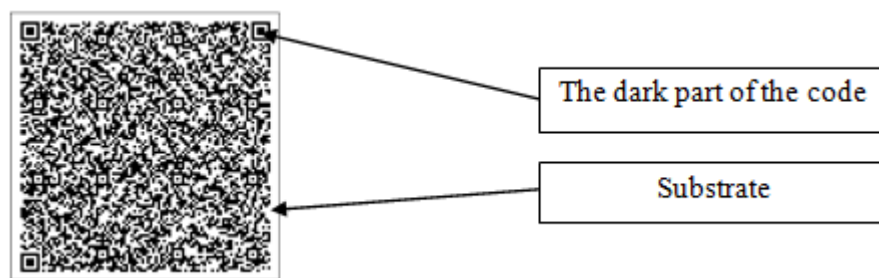


Table 1. Chemical composition of steel 12X18H10

Mass fraction of elements, %							
C	Mn	Si	Cr	Ni	Fe	S	P
≤0,12	≤2,0	≤0,8	17,0-19,0	9,0-11,0	bas.	≤0,020	≤0,035

To perform the laser marking process, the system of precision laser marking "MiniMarker 2-20A4" was used. This is a marker based on an ytterbium pulsed fiber laser with a wavelength of 1.064 μm . The control takes place via a PC with the installed software package SinMark.

The elements of the QR-code on the steel are: the light part (the substrate) and the dark part of the code (Fig. 1). The experiment was planned to achieve the maximum contrast of the QR-code. The substrate was applied in a single mode for all samples, and the code dark part for each sample had individual labeling parameters, such as frequency, power P , speed V , lineage lpi , pulse duration τ .

**Figure 1.** QR-code

In order to obtain data for the study, the QR-code was printed with a resolution of 1200 \times 1200 dpi per paper.

The roughness of the steel surface after laser marking was determined by the Mitutoyo SurfTest SJ-210 profilometer, which works by the direct contact method of a measuring instrument (sensitive element of the instrument) with a controlled surface or with individual irregularities. A portable profilometer is an easy-to-use device, widely used for various surface examinations [12, 13].

The profilometer was used to determine the roughness, the substrate index and the dark portion of the QR code, laser-marked on steel. As the index, the most common roughness surface parameter was chosen - the arithmetic mean deviation of the estimated profile Ra . The study requires a calculation of the index of roughness difference Δ :

$$\Delta = \frac{Ra_{code} - Ra_{substrate}}{Ra_{substrate}} \cdot 100\%, \quad (1)$$

where Ra_{code} – roughness index of the dark part of the code, μm ; $Ra_{substrate}$ – substrate roughness index, μm .

The measuring range of the Ra parameter, which can be determined by the profilometer, is 0.04-100 μm ; the measurement speed is 0.25 mm/s. The base length of the line used to determine the roughness was varied (0.25 / 0.8 / 2.5 mm), depending on the code section being analyzed (substrate or dark part of the code). The location of the line is transverse to the laser passages. A profilogram of a surface area (2.5 mm in length) used to determine Ra was also taken as a profilometer. All the data were transferred using a USB cable from the profilometer to the computer and reflected in the installed Mitutoyo program.

To study the surface structure and to obtain the microstructure steel image under investigation, a compact inverted microscope Leica DM ILM HC was used. It is connected to a PC for displaying information on the monitor screen, taken with a digital camera of a microscope.

3. Results and Discussion

Comparison of calculated data with contrast indices, obtained by the method in Adobe Photoshop, revealed the existence of a direct relationship between the contrast and the roughness difference of the code (Fig. 2) and the possibility of using a profilometer to estimate the contrast. The contrast of the BL pattern (dashed line, Fig. 3) at the level of 80% determines the confident readability of the code. The samples group with readable codes according to the procedure of [9] is identical to the samples group with the roughest surface. The roughness index Δ within this group is above 80%. The different position of sample 2 in the contrast and roughness graph led to the need to determine additional factors for estimating the contrast using a profilometer.

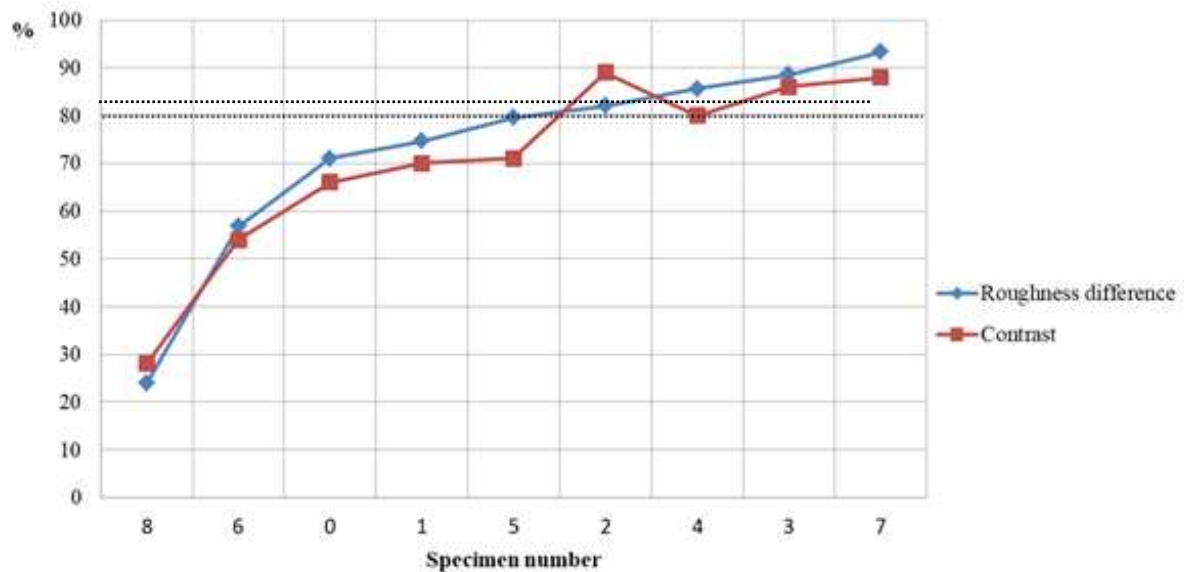


Figure 2. Contrast parameters and roughness difference of the investigated samples in ascending order

Due to laser marking, the initial roughness of the sample was changed; a grooved surface relief was obtained (Fig. 3). According to the profilograms, it is possible to clearly identify the areas of the light (substrate) and the dark part of the code from the change in the grooved surface relief. An increase in the depth of the furrow and the appearance of "hillocks" with increasing intensity of marking the dark part of the code contributes to an increase in the absorptivity, which positively affects the contrast.

The profilograms revealed features of the code surface, which adversely affect the contrast:

- scattering the boundaries of code elements, displayed on the profilogram in the form of a wide peak-polukatera. There is an increase in the area with increasing intensity of laser irradiation (Fig. 4);
- the distance between the furrows as the line is lowered (Fig. 5).

The negative influence of this distance on the contrast is due to the fact that the gaps between the laser passages are more reflective than the furrows. Increasing the intensity of the marking increases the bath of the melt. This causes a violation of the sharpness of the boundaries of the code elements and lowers the contrast. The combination of such conditions as the absence of negative factors and the provision of roughness above 80%, led to the greatest contrast of sample 2 and to differences when compared with the results of another technique.

Thus, the contrast required for reading is estimated by the profilometer using a combination of the following factors:

- roughness difference Δ ,
- distance between laser passages,
- dissipating the boundaries of code elements.

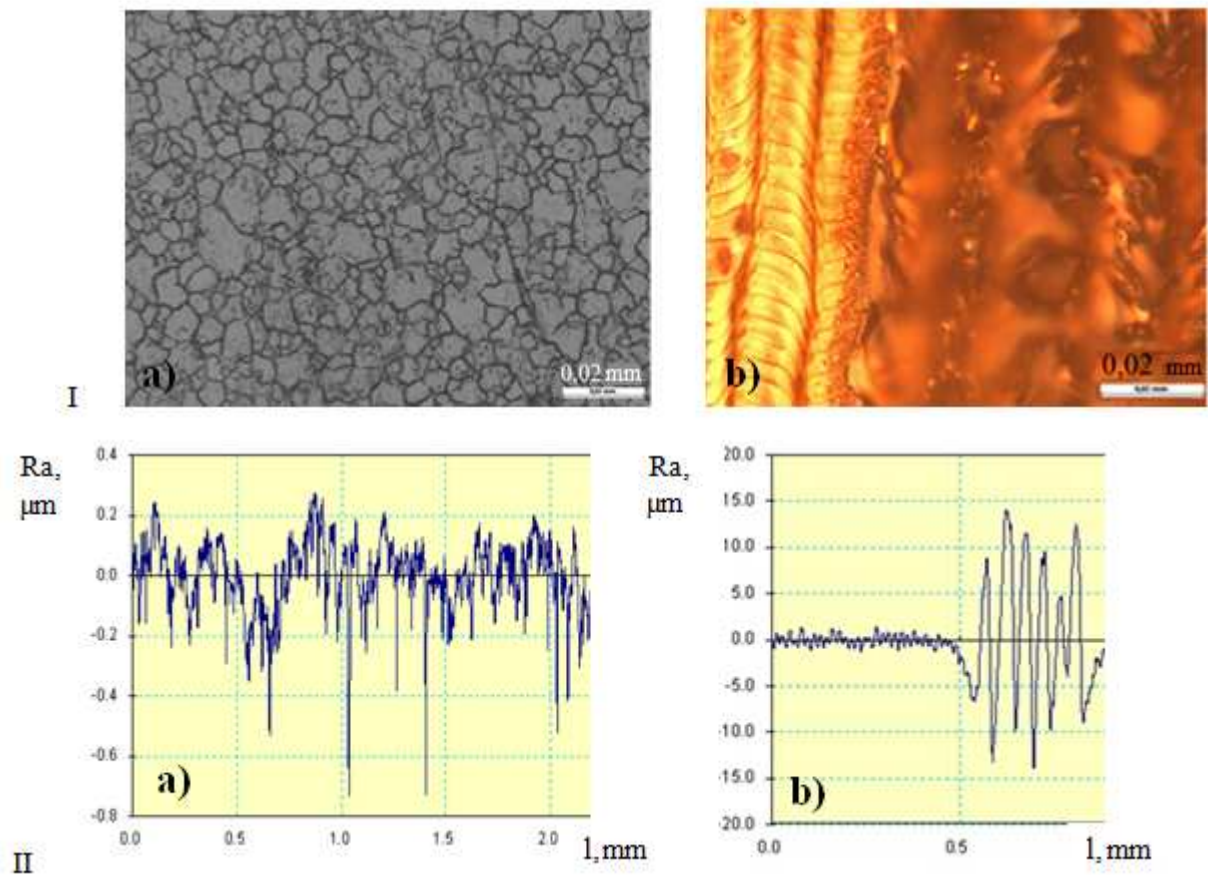
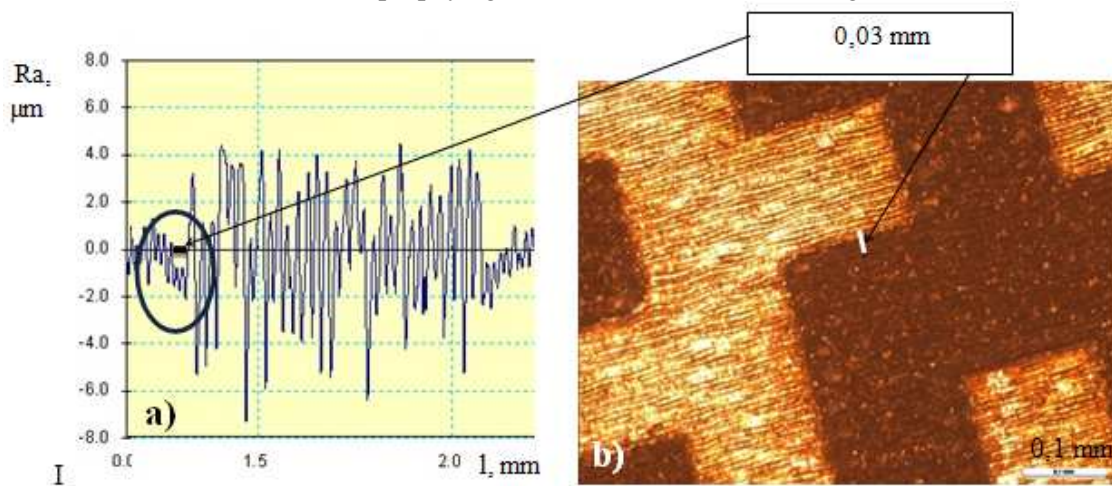


Figure 3. Surface of sample 7: I - microstructure: a) initial, b) after marking;
II - phylogram: a) initial, b) after labeling



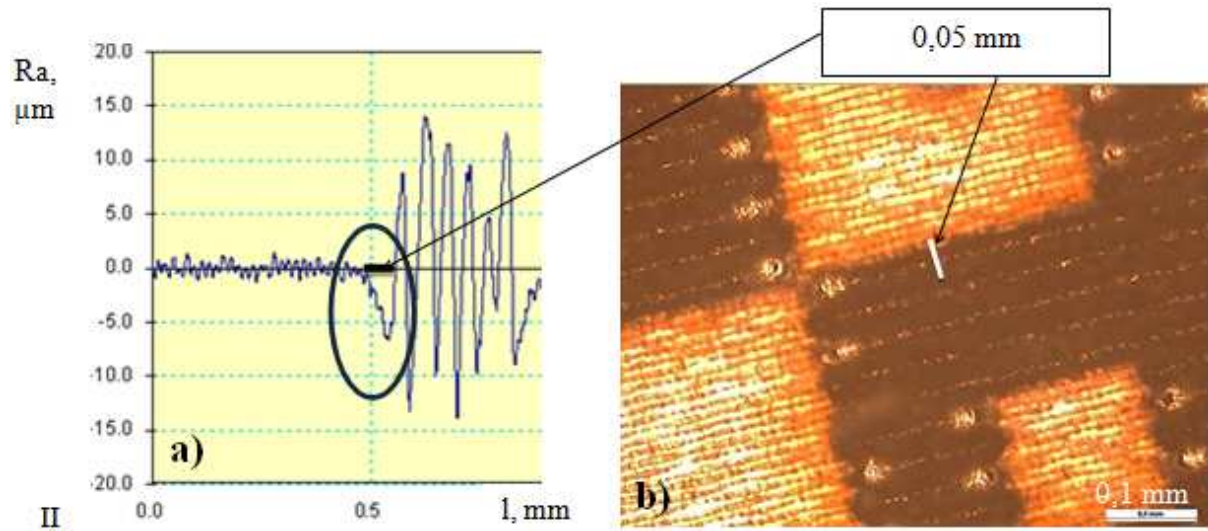


Figure 4. I - sample 7 ($q = 9.06 \cdot 10^{11} \text{ W/m}^2$, $t_{\text{eff}} = 45 \mu\text{s}$): a) profilogram; b) microstructure;
 II - sample 5 ($q = 1.13 \cdot 10^{11} \text{ W/m}^2$, $t_{\text{eff}} = 72 \mu\text{s}$): a) profilogram; b) microstructure

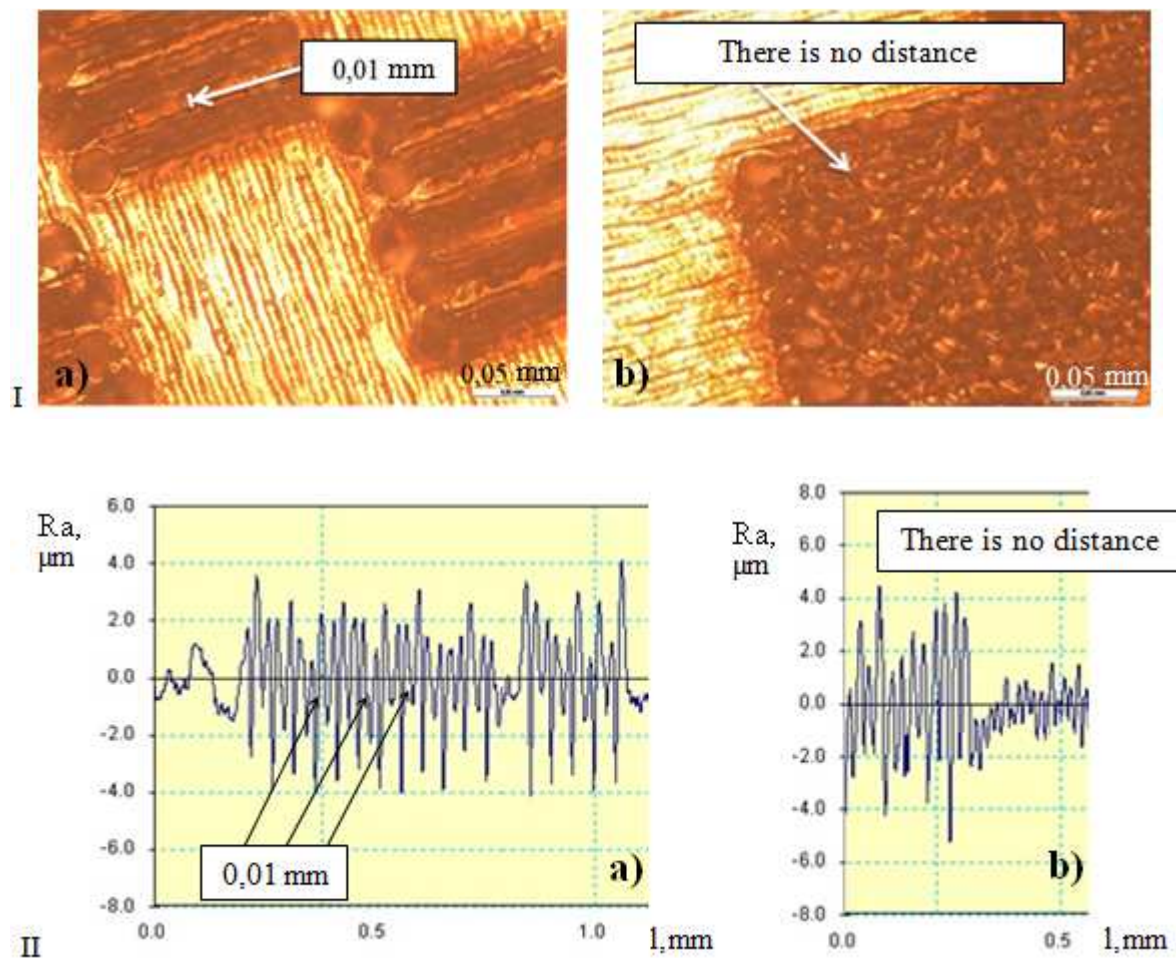


Figure 5. Distance between grooves for samples - a) No. 1 ($\text{lpi} = 20 \text{ lines/mm}$);
 b) No. 5 ($\text{lpi} = 40 \text{ lines/mm}$): I - microstructure; II – profilogram

4. Conclusion

Evaluation of the contrast of laser marking with a profilometer is a new technique; its basis is the recently revealed dependence of the contrast of the code on the roughness and the study of profilograms of the metal surface complex relief. The technique is shown on stainless steel - a widely applicable material in various industries. The simplicity and accessibility of the methodology facilitates its implementation in machine-building plants, in the mining industry to determine the quality of marking on products and equipment [14-18].

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