Development of a fast method for forming Braille on the surface of steels with IR ns-pulsed 50 W fiber laser

J V Amiaga¹, S A Vologzhanina¹, B S Ermakov² and S G Gorny³

¹ Saint Petersburg National Research University of Information Technologies, Mechanics and Optics University ITMO, 49, Kronverksky Pr., Saint Petersburg, 197101, Russia
² Peter the Great St. Petersburg Polytechnic University, 29, Politekhnicheskaya St., Saint Petersburg, 195251, Russia
³ Laser Center LLC, 25, Piskarevsky ave., Saint Petersburg, 195176, Russia

E-mail: Joong@yandex.ru

Abstract. Convex linear structures of various configurations with a height of up to 200 microns and a depth of up to 100 microns, point structures with a height of up to 500 microns were obtained on the surface of the steel using a 50 W 1.064 μm wavelength fiber laser source. No additives were used. The structures were formed from the material of the irradiated steel by controlling the dynamics of the melt. The possibility of forming Braille on a steel surface using this technology is demonstrated. The results are encouraging for a number of industry sectors where electron beam machines and high-powered laser sources are cost prohibitive, and one need a high rate of obtaining relief.

1. Introduction

In recent years, the research trend has been gradually shifting toward studying the capabilities of lasers with short and ultrashort pulses (pico- and femtosecond). There are a number of works devoted to laser ablation performance or material removal rate [1,2]. Leitz et al. compared micro-, nano-, pico- and femto-second sources of laser radiation in light of the rate of removal of material in the receiving holes process [1]. Authors reported that among the investigated laser systems the nanosecond one allows highest ablation efficiency per energy. Traditionally, the presence of splashes of the liquid phase and burr at the edges of the holes in the ablation process is undesirable. This reduces the efficiency of the process and also the quality of the holes or other technological operations. Generally, increasing ablation rate leads to increasing the amount of liquid phase in its turn decreasing quality of the microstructuring.

In [3,4] liquid phase control is included in the process. Moreover, the presence of a melt is an advantage [4]. In [3] the authors obtained surface diffraction structures using radiation of nanosecond duration with a wavelength of 1.064 μm. It was achieved by melt control in micron size areas. In [4], the authors obtained various stable structures on the surface of steel using a 200 W CW Yb-fibre laser with a height of the order of 1 mm without the use of filler materials. Moreover, authors used their own trademark process called Surfi-Sculpt®.

The aim of the work was to find out the optimal strategy for steel surface laser treatment to obtain a stable relief with a maximum height difference (engraving depth, surface structure heights, total
difference) using a low-power laser source (50 W) with a wavelength of 1.064 μm. Also we demonstrate the capabilities of a steel treatment strategy with pulses of a nanosecond laser, according to which the liquid phase is not unwanted, but useful.

2. Experimental details

2.1. Material and system

The normal quality of structural carbon steel of grade St3ps (Russian grade abbreviation) was used as a material for investigation. The chemical composition in % for grade St3ps is given in table 1.

|   | C    | Si   | Mn  | Ni  | S    | P    | Cr  | N   | Cu  | As  |
|---|------|------|-----|-----|------|------|-----|-----|-----|-----|
|   | 0.14 | 0.05 | 0.4 | max | max  | max  | max | max | max | max |
|   | 0.22 | 0.15 | 0.65| 0.3 | 0.05 | 0.04 | 0.3 | 0.008| 0.3 | 0.08|

A 1-5 mm thickness sheet of leads of the St3ps (GOST 3778-77) were used as samples for investigation.

The steel sheet was processed by 1.064 μm laser irradiation. The laser source was YPLN-1-100-50-M (IPG Photonics). The laser source was integrated in the laser system (TurboMarker, Laser Center LLC) with a scanner head. The general specifications of the laser system is listed in table 2. The scanner head was equipped with an f-theta lens. The calculated beam diameter was 75 μm. The system could reach up to 15000 mm/s of scan speed (v). The laser could generate up to 50 W of average power (P_avg) and could be operated between 2-200 kHz of the pulse repetition rate (PRR) range. The appearance and structure of the laser system are shown in figure 1.

| Brand and model | YPLN-1-100-50-M |
|-----------------|-----------------|
| Architecture    | Fibre, Q-switched |
| λ               | 1064 nm         |
| Max P_avg       | 50 W            |
| PRR             | 2-200 kHz       |
| Max. E          | 1 μJ            |
| τ               | 100 ns          |
| beam quality, M²| <2              |
| d0              | 75μm            |

Figure 1. The appearance of the laser system including: (1) – scanner head, (2) – f-theta lens, (3) – control system and laser source
The relief was inspected through optical microscopy and relative measurements were taken using the images obtained via a digital camera.

2.2. Experimental plan
The first step was to determine how the melt behaves near the rectilinear groove if the beam path does not coincide with the direction of the groove. It was necessary to determine the optimal regimes of laser radiation in which it is possible to effectively control the melt during laser exposure to steel. For the laser source YPLN-1-100-50-M, the maximum pulse energy is 1 mJ. This energy is possessed by pulses which are emitted at a frequency of 50 kHz. These values of these parameters are widely used in obtaining fast relief using engraving in the evaporative mode using this laser emitter. These two parameters were unchanged.

Then the speed of the laser beam on the surface is the first parameter in the problem. It is widely known that when performing welds with electric arc welding, transverse vibrations of the electrode along a certain path are used, performed with a constant frequency and amplitude and combined with movement along the seam. Such movements make it possible to control the melt and the degree of heating of the welding areas, and to obtain a weld of the required width and quality. To control the melt in the problem of the article, the rectilinear motion of the beam was replaced with motion along a curve called a trochoid. There are two parameters for this curve: the cyclic frequency and the width of the curve. For convenience, we will study not the cyclic frequency, but the distance between the loops of the trochoid. We have three parameters for the study of obtaining linear convex structures on the surface of steel: the speed of the beam (\( V \)), the width (or height) of the trochoid (\( H \)), the distance between the loops (\( D \)).

After finding the optimal parameters of the trochoid and the speed of the beam, it was necessary to study how the shape of the guide curve affects the result. Drawing an analogy with electric arc welding, it can be called a curve responsible for the shape of the weld. It was a second step in the study. Figure 2 shows a diagram on which there are all the parameters of the task.

![Diagram with parameters of the task and beam motion pattern](image)

**Figure 2.** Diagram with parameters of the task and beam motion pattern, where D – the distance between the loops, V – the speed of the beam, H – the width (or height) of the trochoid.

3. The study of the 1-dimensional structures on the steel surface
It was discovered that the trochoid movement of the laser beam on the steel surface leads to the formation of the groove and a side bead consisted of re-solidified steel. For a more detailed analysis of the relief, metallurgical grindings were produced. The cross section of these linear structures has an N-shape as can be seen in figure 3. Further, studies were conducted on the influence of the task parameters on the shape and stability of the N-structure. For better understanding of the results of the experiments, side light was used and N-structures were additionally treated with a special cleaning treatment on the same laser system. Side light gives a shadow by which one can estimate the depth of the groove, height of the beads and their stability. The cleaning treatment allows one to remove oxides.
and slightly melt the surface to a metallic luster. Figures 4-6 contain a special sign indicating the light source position.

**Figure 3.** N-shape grooves on the steel surface. Cross section view

Decreasing the beam speed from 300 to 150 mm/s leads to increasing of the groove depth and bead height, decreasing the width of the groove. When the speed is equal to 100 mm/s, the bead moves closer to the center of the groove as the groove collapses. Moreover, the height of the bead decreases, as can be seen from figure 4. Increasing the distance between the loops from 5 μm to 15 μm leads to increasing the groove depth and bead height. Increasing the distance between the loops from 15 μm to 25 μm leads to decreasing the groove depth and collapsing the groove as can be seen in figure 5. Increasing the width (or height) of the trochoid from 0.3 mm to 0.4 mm leads to increasing the groove depth and bead height. Increasing the width from 0.4 mm to 0.5 mm leads to decreasing the groove depth. When the width is equal to 0.5, the bead becomes unstable and breaks up into individual drops, the groove collapses as can be seen in figure 6.

Based on the results obtained, one can conclude that the optimal parameter values are V=150 mm/s, D=15 μm, H=0.4 mm.

Combining the resulted structures, one can obtain other structures schematically depicted in figure 7. It is necessary to know where the melt is directed during the laser process. Figure 7 shows it. The appearance and cross section of Λ-, π- and M-structures are given in figure 8. These structures can be used to convex text marking on a steel surface.

**Figure 4.** N-structures on the steel surface. Top view. Speed of the beam is reduced from left to right
Figure 5. N-structures on the steel surface. Top view. The distance between the loops increases from left to right.

Figure 6. N-structures on the steel surface. Top view. The width (or height) of the trochoid increases from left to right.

Figure 7. Scheme for obtaining various one-dimensional structures. Ray and melt motion pattern, where (1) – direction of melt travel, (2) – groove on the steel surface, (3) – beam path (a trochoid), (4) – guide path.
Figure 8. View of the various one-dimensional structures. (a) – Several lines of all three structures, top view. Cross section views: (b) – Λ-structure, (c) – π-structure, (d) – M-structure

4. The study of the point structures on the steel surface. Braille
It was found that if the Archimedes spiral is used as a guide path as shown in figure 9, it is possible to obtain point structures shown in figure 10. To be more precise, an additional circle was needed for the guide path. These point structures are easily tangible with the fingertips and can be used as Braille on the steel surface as shown in figure 11. The height of the point structures is 500 μm. The time required for drawing the text string “HELLO WORLD” was 4.5 min, for Braille text – 5 min. Point structures were additionally treated with a special cleaning mode on the same laser system. Linear structures were additionally machined manually to a metallic luster.
Figure 9. Beam path for obtaining the point structure from the control program window of the laser system: (a) – true beam path, (b) – enlarged area, (c) – simplified path scheme, where circle and Archimedean spiral are a guide path, the transparent line is a beam path.

Figure 10. View of point structures: (a) – side view of point structure, (b) top view of several point structures arranged in the shape of braille font ligature «for».

Figure 11. View of the convex text and braille text with the same characters.
5. Conclusion
Basic results:
1. The possibility of controlling the melt and obtaining convex stable structures when processing the surface of a steel with low-power nanosecond laser radiation was investigated.
2. It was clarified how the main processing parameters affect the structure of convex linear structures. The optimal parameters were found.
3. Point structures were received on the steel surface. These structures satisfy the requirements of Braille.
4. The maximum value of the height difference was 300 μm for linear structures and 500 μm for point structures.

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