The use of laser radiation for cutting of blind grooves and small-sized through cuts in thin-walled cylindrical bodies

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Abstract. The issues of optimization of technological parameters of laser treatment of radio engineering products for the formation of narrow through cuts and blind grooves at shell spheres are considered. The laser marker not performing such operations is used as the main technological equipment. The possibilities of a laser marker for getting narrow through cuts are shown in the paper. The modes of getting cuts at the samples made of D16T, 12Cr18Ni10Ti and steel 45 are selected and optimized.

The problem of precision laser treatment is to determine the optimal parameters of high-energy laser treatment of processes to create small (microns) geometric dimensions of the cut. This problem is determined to a considerable degree by thermodformation processes and structural transformations in metals under the treatment of laser radiation [1-4], but various technological issues arise while the practical implementation of such processes.

The purpose of this paper is to study the influence of energy parameters of pulsed laser radiation on the process of forming small-sized through cuts with width no more than 100mkm. Also it is necessary to study the cutting of blind grooves in thin-walled shells at the element base of radio engineering.

Two tasks connected with the goal are formulated in the paper.

The first task is to determine the energy modes of laser beam treatment while the production of precision parts.

The second task is to determine the technological parameters to obtain the specified geometry and microstructure of the material in the cutting area.

The solution of the first task is to make a through hole in parts with a wall thickness of 0.3 mm made of aluminum alloy D16T, State Standard 4784-2019 and 0.2 mm made of steel 12Cr18Ni10Ti, State Standart 5632-2014.

The second solution is to make blind grooves in parts with a wall thickness of 4.0 mm made of 45 steel, State Standard 1050-2013 pre-subjected to various heat treatment.

The analysis of the macro-, microstructure and dimensions of the cut was made at the following equipment:

- Stereoscopic microscope MBS-9 TU 3-3-1210-78;
- Universal digital microscope Keyence VHX-1000;
- Norgay NVM-3020D video measuring system.
Energy modes of laser beam treatment while the manufacturing of precision parts.

The stationary laser system "LDesigner F2" is used in the paper, equipped with numerical control, Figure 1, Table 1.

![Stationary laser marking system.](image1)

**Figure 1.** Stationary laser marking system.

**Table 1.** Characteristics of the laser emitter.

| Type                              | Pulsed ytterbium fiber laser |
|-----------------------------------|------------------------------|
| Radiation wavelength              | 1.06…1.07 micron             |
| The maximum average radiation power| 60 W                        |
| Pulse duration                    | 100 nanoseconds              |
| Pulse frequency                   | 1,6…1000 kHz                |
| Cooling                           | air                          |

The experiments were performed without gas supply to remove the molten material and its evaporation products from the treatment area during metal cutting and protect the metal from oxidation. It is difficult to remove heat from the cutting area. It increased the area of thermal influence on the cut metal, especially in the deep part of the formed groove.

While the experiments the controlled parameters of the "LDesigner F2" complex were:

- laser power supply - 3 ... 60 W;
- the speed of the laser beam on the surface of the product - 1 ... 50 mm/sec;
- delay 1 for switching on the radiation - 0.3-1.0 miliseconds;
- delay 2 for switching off the radiation - 0.8 ... 1.2 miliseconds;
- delay 3 for movement (waiting time between the start of movement of the scanners and the switching on the radiation) - 0.3 ... 0.7 miliseconds;
- frequency of laser radiation modulation - 1600 ... 1000000 Hz;
- ratio of ray spinning - 0,001...1,000;
- number of laser pulses when marking a point - 1...100 000;
- number of repetitions of working passes - 5 ... 100.

The results of experiments of laser treatment of D16T alloy selected as a result of optimization are presented in Table 2 and Figure 2.
Table 2. The modes of laser treatment of alloy sample of D16T.

| № sample | Figure, plate side | Parametres of laser treatment | Cutting width, microns |
|----------|--------------------|-------------------------------|------------------------|
|          |                    | Laser power, W | Laser speed, mm/sec. | Modulation frequency of radiation, Hz | Number of pulses, pulse | Number of passes |                      |
| 1        | 2 a), input        | 20              | 0,1                   | 50 000                      | 1                     | 10             | 160                    |
| 2        | 2 b), input        | 20              | 0,1                   | 60 000                      | 1                     | 10             | 234                    |
| 3        | 2 c), input        | 16              | 0,1                   | 2 000                       | 1                     | 10             | 73                     |
| 4        | 2 d), input        | 20              | 0,1                   | 1 600                       | 1                     | 20             | 90                     |
| 5        | 2 e), output       | 20              | 0,1                   | 2 000                       | 1                     | 20             | 22                     |
|          | 2 f), input        | 16              | 0,1                   | 20 000                      | 1                     | 20             | 46                     |
|          | 2 g), output       | 16              | 0,1                   | 20 000                      | 1                     | 20             | 18                     |

Figure 2. The surface of the samples in the cutting zone D16T: a) beam input, ×300; b) beam input, ×160; c) beam input, ×300; d) beam input, ×500; e) beam output, ×500; f) beam input, ×700; g) beam output, ×700.
The results of experiments of laser treatment of steel 12Cr18Ni10Ti selected result of optimization are presented in Table 3 and Figure 3.

**Table 3.** The modes of laser treatment of steel sample of 12Cr18Ni10Ti.

| № sample | Figure, plate side | Parameters of laser treatment | Cutting width, microns |
|----------|--------------------|-------------------------------|------------------------|
|          |                    | Laser power, W | Laser speed, mm/sec. | Modulation frequency of radiation, Hz | Number of pulses, pulse | Number of passes | |
| 6        | 3 a), input        | 20              | 0.1                  | 1600                             | 1                        | 20             | 68 |
|          | 3 b), output       |                 |                      |                                  |                          |                | 32 |
| 7        | 3 c), input        | 16              | 0.1                  | 20000                            | 10000                    | 20             | 67 |
|          | 3 d), output       |                 |                      |                                  |                          |                | 29 |

**Figure 3.** The surface of the samples in the cutting zone 12Cr18Ni10Ti: a) beam input, ×300; b) beam output, ×300; c) beam input, ×700; d) beam output, ×700.

The analysis results of the groove width depending on the frequency of laser radiation modulation at optimal parameters are shown in Figure 4:

- Laser power supply 16 W;
- Laser speed 0.1 mm/s;
- Delay 1-0.9 milliseconds;
- Delay 2-1.05 milliseconds;
- Delay 3-0.45 milliseconds;
- Ratio of ray spinning - 0.05;
- Number of pulses when marking a point - 1;
- Number of passes - 20.

As a result of the study it was found that the purity of the through a gap cut from the shielding effect of the formed oxides depends mainly on the frequency of the laser radiation modulation. At frequencies of 10, 40 – 60 kHz there is a significant heating of the sample; as a result the groove width increases.
and the quality of the groove edges deteriorates. At modulation frequencies less than 10 kHz the metal oxides on the samples surface is formed.

**Figure 4.** Dependence of the groove width on the modulation frequency

Technological parameters for the blind grooves of a given geometry and microstructure of the material in the cutting area.

To test the laser cutting technology of blind grooves for products made of 45 steel with pre-heat treatment to create a different microstructure, a CO2 laser "Comet-2" was used in a continuous mode of laser radiation with a focused focal spot with diameter of 0.2 mm.

The purpose of blind grooves is to form surface cuts with simultaneous thermal hardening of their edges. They serve as stress concentrators necessary to control the destruction of the cylindrical shell with different initial microstructure and the level of hardness of the material, Table 4.

**Table 4.** Heat treatment modes and properties of steel 45.

| Sample № | Heat treatment | Hardness, HRC | Microstructure |
|----------|----------------|---------------|----------------|
| №1       | The original state, hot rolled | 21-23 | coarse-grained ferrite + perlite |
| №2       | Normalization 850°C, exposure time 10 min., air cooling. | 18-20 | fine-grained ferrite + perlite |
| №3       | Hardening 850°C, exposure time 10 min., water cooling. Release 200°C, exposure time 1 hour. | 43-45 | martensite |

The results of experiments of applying blind groove are shown in Table 5 and Figure 5.

**Table 5.** Modes of laser treatment of steel samples 45.

| Sample № | Figure | Laser treatment parameters | Groove width, mm | Groove depth, mm | Width of the thermal influence area, mm |
|----------|--------|-----------------------------|------------------|------------------|----------------------------------------|
| №1       | 5a     | Laser power, W | 1000 | 25 | 0,2 | 1,9 | 0,1...0,2 |
| №2       | 5b     | Laser power, W | 1000 | 34 | 0,2 | 1,7 | 0,15...0,60 |
| №3       | 5c     | Laser power, W | 1000 | 34 | 0,2 | 1,7 | 0,1...0,5 |

It is found that in all cases of laser treatment, a thermal influence area is formed at the edges of the cut groove; in this phase transformations take place (martensite formation) and, as a result, the material is hardened. In all cases, the microhardness of the transition area is HV3500-4000 MPa. These values are close to the microhardness of 45 steel in the hardened state (HV 4000-4500). The formation of a hardened edge inside the cut blind grooves and especially in the form of a closed area at the bottom of the groove embrittles the steel; it leads to a decrease in the material's resistance to the impact of
destructive mechanical forces. The blind cut is a stress concentrator, an embrittled layer inside the groove reduces the structural strength of products in a given direction, especially when applying dynamic forces.

![Figure 5. Type of steel 45 samples in the cutting zone, ×700.](image)

**Conclusions**

1. The obtained study results show the possibility of using the laser treatment unit "LDesigner F2" (marker) to perform narrow through grooves with a width of 20-100 microns in structural elements made of D16T alloy and 12x18n10t steel for the "optical collimator" type.

2. The effect of laser thermal hardening in steel 45 when cutting the blind grooves regardless of the type of the original microstructure reduces its crack resistance.

3. The formation of blind grooves of steel 45 shells with hardened contour surfaces controls the local destruction of products under a given mechanical impact.

**Acknowledgments**

The work was performed at the NSTU named after R. E. Alekseev under an Agreement with PJSC Ruspolimet dated September 20, 2019. No. 19/2504/83-04/1075/19 with the financial support of the state represented by the Ministry of science and higher education of the Russian Federation under the agreement of December 18, 2019. №075-11-2019-084 (state contract ID 0000000007519SZB0002), subject: "Creation of high-tech production of materials, products and equipment using additive technologies and gas-cooling technologies on the basis of PJSC RUSPOLIMET."

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