The effects of beam oscillation on the quality of laser deposited metal parts

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Abstract. Nowadays, additive technologies are one of the most fast developing methods of obtaining products. The greatest interest is the technology of high-speed direct laser deposition (HSDLD), when a gas powder stream is fed into the laser radiation zone, as a result, a melt pool is formed, and then a layer – after hardening. Thus, it becomes possible to produce threedimensional products with complex geometry with high productivity. The most promising industries for the application are aircraft engine building and shipbuilding. The modern aircraft engine industry has lots of elements that are more preferable to be manufactured by the HSDLD technology: large-sized products with wall thickness ≥ 3 mm, material Ti-6Al-4V, in particular. The main requirements for these parts are high performance properties, namely pore minimization, absence of cracks and non-fusions between the layers, low surface roughness to reduce subsequent machining.

1. Introduction
The industrial usage of titanium alloys is increasing due to an efficient combination of high specific strength and heat resistance properties (up to 400-600 °C). Titanium alloys have high corrosion resistance in most environments [1-4]. Machining of titanium alloys is difficult due to the low thermal conductivity and sticking of the materials to the tool [5]. HSDLD is a promising method of manufacturing details with minimal subsequent machining [6-8].

It was revealed that with Gaussian beam distribution in thin element non-fusion on the edges is formed (figure 1). These defects become the stress concentrators and significantly reduce the mechanical properties of details.

Figure 1. Non-fusion on the edges with Gaussian beam distribution
Analyzing the possible solutions helped to find out the necessity of using a wobbler or beam shaper to achieve the required properties. As a result, wobbler was used for the research, because unlike the beam shaper, it has a great functionality and the possibility of changing the wall thickness, by changing the scanning amplitude within the deposition process.

2. Experimental procedure

2.1 Technological complex
The research was carried out with the help of the laser metal deposition robotic complex, based on the fiber laser "LS-5". The complex also includes a six-axis robot manipulator, a two-axis positioner and a sealed chamber with a 6 m³ volume. The working tool is the laser welding head D 30 Wobble Module of IPG Company with a three-jet nozzle. The figure 2 shows robotic complex:

![Robotic complex for HSDL](image)

**Figure 2.** Robotic complex for HSDL

Welding head D 30 Wobble Module is equipped with a 2-axis scanner and allows to scan the laser beam with a maximum amplitude of 2.5 mm and a frequency of 300 Hz. The figure 2 shows the scanator’s scheme:

![Welding head D 30 Wobble Module](image)

**Figure 3.** Welding head D 30 Wobble Module
The optimal shape of scanning is a line (scanning is performed perpendicular to the direction of the material deposited). When the scanning is linearly the beam stops at the extreme points of its trajectory. [9]. That leads to an increase of the heat input, which prevents non-melting at the edges.

2.2 Technological experiments
Criteria for the optimal technological parameters are:

- wall thickness is ≥ 3,3 mm (there are many details in the aircraft building based on the thin wall (≈ 3 mm));
- process stability;
- defect minimization (pores, non-melting, cracks);
- roughness minimization, for minimal subsequent machining.

During the experiment the following technological parameters were varied (table 1):

| №  | Laser power (W) | Velocity (mm/s) | Spot diameter (mm) | Scanning amplitude (mm) |
|----|----------------|-----------------|--------------------|-------------------------|
| 1  | 1700           | 20              | 2                  | 2.5                     |
| 2  | 1500           | 20              | 2                  | 2                       |
| 3  | 1300           | 20              | 2                  | 1.5                     |
| 4  | 1200           | 20              | 2                  | 1                       |
| 5  | 2000           | 30              | 2                  | 2.5                     |
| 6  | 1800           | 30              | 2                  | 2                       |
| 7  | 1500           | 30              | 2                  | 1.5                     |
| 8  | 1300           | 30              | 2                  | 1                       |
| 9  | 1900           | 20              | 2.5                | 2.5                     |
| 10 | 1800           | 20              | 2.5                | 2                       |
| 11 | 1700           | 20              | 2.5                | 1.5                     |
| 12 | 1400           | 20              | 2.5                | 1                       |
| 13 | 2100           | 30              | 2.5                | 2.5                     |
| 14 | 2000           | 30              | 2.5                | 2.5                     |
| 15 | 1700           | 30              | 2.5                | 2.5                     |
| 16 | 1700           | 30              | 2.5                | 1.5                     |
| 17 | 2100           | 20              | 3                  | 2.5                     |
| 18 | 2000           | 20              | 3                  | 2.5                     |
| 19 | 1900           | 20              | 3                  | 1.5                     |
| 20 | 1800           | 20              | 3                  | 1                       |
| 21 | 2300           | 30              | 3                  | 2.5                     |
| 22 | 2200           | 30              | 3                  | 2                       |
| 23 | 2300           | 30              | 3                  | 1.5                     |
| 24 | 2200           | 30              | 3                  | 1                       |
The samples are 40 mm long and 20 mm high. Figure 4 shows the process HSDL:

![HSDL process](image)

**Figure 4.** HSDL process

### 2.3 Measuring samples

After fabrication the thickness and roughness of all the samples is measured. The contact profilometer Hommel tester W55 (figure 5) was used for measuring roughness.

![Hommel tester W55](image)

**Figure 5.** Hommel tester W55

The trace length was chosen to be 4.8 mm as the optimal value for measuring the small samples. The probe movement speed was set to 0.5 mm/s.

The roughness and thickness of the samples are shown in the table 2:
**Table 2.** The roughness and thickness of the samples

| №  | Ra (μ) | Thickness (mm) |
|----|--------|----------------|
| 1  | 16,07  | 3,4            |
| 2  | 26     | 2,9            |
| 3  | 21,06  | 2,7            |
| 4  | 21,71  | 2,5            |
| 5  | 14,48  | 3,4            |
| 6  | 23,5   | 3              |
| 7  | 23,7   | 2,6            |
| 8  | 25,48  | 2,4            |
| 9  | 13     | 3,6            |
| 10 | 11,2   | 3,4            |
| 11 | 13,63  | 3              |
| 12 | 23     | 2,6            |
| 13 | 10,89  | 3,2            |
| 14 | 12,64  | 3,1            |
| 15 | 14,9   | 2,7            |
| 16 | 27,48  | 2,4            |
| 17 | 7,72   | 3,6            |
| 18 | 16,19  | 3,4            |
| 19 | 19,4   | 3              |
| 20 | 23,48  | 2,7            |
| 21 | 7,76   | 3,3            |
| 22 | 14,48  | 3,2            |
| 23 | 20,89  | 2,8            |
| 24 | 24,5   | 2,5            |

Figure 6 reflects the results graphically:
Figure 6. The roughness and thickness graphically (ds-diameter spot)

2.4 Result analysis
As it is shown on the figure 6, there is a correlation between the scanning amplitude and the roughness. With the increase of the scanning amplitude, roughness is reduced.

The extreme point of the previous layer remelt A’ becomes farther from the center and lower than the point A (figure 7). Due to the additional scanning it becomes possible to remelt the edges of the previous layers.
Conclusion
As a result of this work, technological experiments were conducted to fabricate a thin wall with a Wobbler. It was found that additional scanning of the laser beam leads to a decrease of the roughness. It is possible to produce details with a thickness of $>3$ mm with a minimum number of defects and minimum roughness value. The next step of this research will be the study of the mechanical properties of samples fabricated.
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