

# High-Speed Direct Laser Deposition: Technology, Equipment and Materials

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**Abstract.** The article presents the principles of direct metal deposition process, types of technological equipment and materials for implementation. The samples of deposited products have been demonstrated.

## 1. Introduction

Implementation of high production additive technologies, including high-speed laser direct deposition in the production cycle can significantly reduce the cost of manufacturing high-tech products. Reducing the cost by saving material and reducing the time of manufacture is one of its main advantages over machining on CNC machines or technology of casting with further machining. This is due to the fact that the product is created in one step and the original data for it is a computer model of the product. The need to design technological processes, special machining attachments, special tool and the manual labor eliminates and the duration of the time-consuming process of three-dimensional milling of the working profile of die tooling for CNC machines decreases. This method has a high flexibility, allows to consider multivariate technological and design solutions. It allows to combine it with other technologies, including additive, for example, with selective laser sintering (melting). Another important feature of such technologies is the proximity of the producing shape of a product to defined shape. This significantly reduces consumption of materials and production waste. Because of this, the process of high-speed direct laser deposition in comparison with the traditional production technologies has significant potential in terms of reducing costs, saving energy and reducing harmful emissions into the atmosphere. The process is used in various industries [1,2], mainly due to the high performance (0,5-2 kg/h), also research in the field of high-performance laser powder cladding [3-5] allow to forecast the further increase of productivity of the deposition process up to 15 kg/h.

The results of the research high-speed direct laser deposition of metallic products using radiation of a fiber laser demonstrated in this work.

## 2. Technology of high-speed direct laser deposition

Technology of high-speed direct laser deposition is method of forming metal product due to the partial melting by laser beam of the substrate and the powder transported in a compressed gas-powder jet towards the surface of substrate, coaxially or at an angle to the laser beam [6]. The substrate when melted forms a liquid molten pool of the minimum depth. The metal powder is transported to the substrate and partially melted to form the bead. The solid product is formed by layering on each other. Its geometry is determined by the technological trajectory of the moving head relative to the product.



There is an opportunity during the process to change the composition of the mixture of feed powders. It provides for the formation of products with graded properties.

During performance technologic experiments in laser deposition varied power of laser radiation, deposition rate of layer, depend up rotation rate of substrate and rate of stepwise rise focusing head for generation next layer, flow rate of powder, spot diameter of laser beam, and angle of incident of powder. As a result of research, the parameters of process have identified. They allow to achieve a maximum material ratio for powder and provide the heterophase mechanism of creation of layer with partial melting of metal particles resulting in an increase in the mechanical properties of the product compared with the casting techniques and selective laser sintering or selective laser melting.

### 3. Experiment equipment

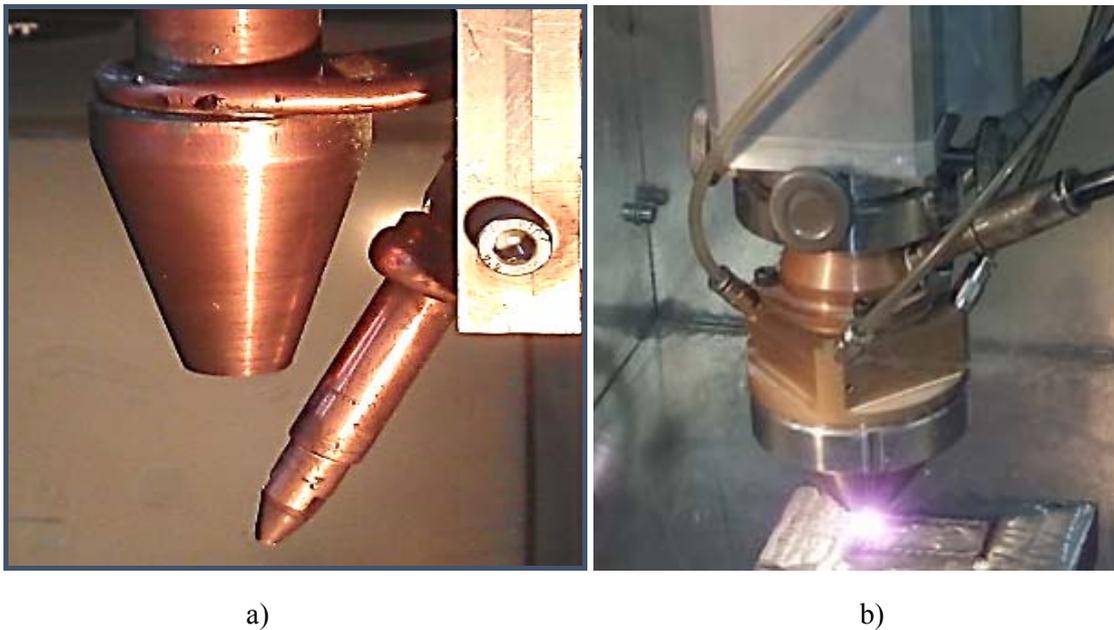
The experimental studies of the processes high speed direct laser deposition have been carried out at the Institute of Laser and Welding Technologies SPbPU(ILWT) using laboratory bench based on fiber laser LS-5 with power output 5kW (see figure 1). The laboratory bench had five axes to move in the process of deposition of the product. The gas-powder mixture was formed by disk powder feeder Sultzer Metco Twin 10-c. For creation of the samples were applied to the shielding chamber and rotator. The gas protection of the weld metal was carried out by argon, supplied in the shielding chamber.



**Figure 1.** Laboratory bench for studies of the process high-speed direct laser deposition.

The main working part of the equipment for direct laser deposition is a working tool. It is a complex device consisting of a laser head including a focusing system of the laser beam and the cooling system of head, the system of feed of the powder material (nozzle) and the elements of the monitoring and control system of the process of deposition (sensors, video cameras, etc.) [7,8].

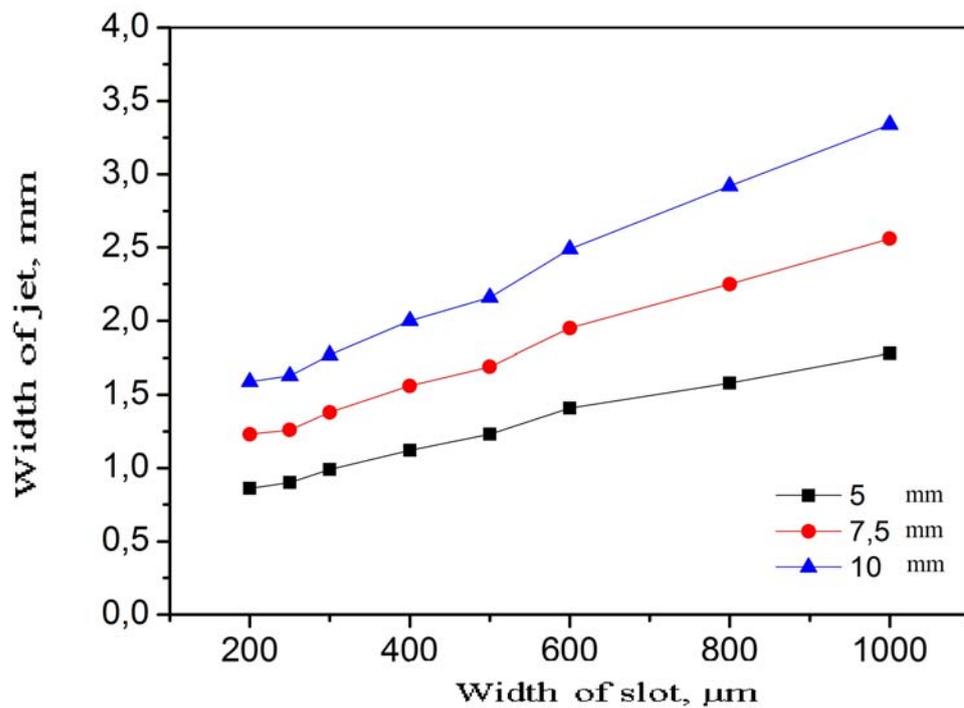
The most important part of working tool is the nozzle for feeding of the powder material. It creates the required distribution of powder in the gas powder jet. Research of formation of gas powder jet and gas-dynamic processes of transfer of powder have been carried. Different designs of nozzles were developed and tested (see figure 2).



**Figure 2.** Nozzles for feeding the powder to the zone of laser action: a) Noncoaxial nozzle of circular cross-section with the diameter of outlet port: 1 mm, 1.2 mm, 2 mm; b) Coaxial annular nozzle with the diameter of the ring 14 mm, the width of the slot is 0.4 mm.

The use of noncoaxial nozzles (figure 2a) leads to the dependence of the process of deposition from the direction of motion, because the nozzle has an asymmetry relative to the direction of movement of the working tool. Therefore, the process should be implemented in a single direction relative to the product. The gas-powder jet is simple in structure and symmetric relative to the canal centerline. The using of noncoaxial nozzles efficiently for deposition of products of complex geometry with axial symmetry or bodies of rotation with a minimum diameter of 6mm. The thickness of wall of the deposition product is in the range of from 0.6 to 3 mm with a roughness of surface is not more than 50  $\mu\text{m}$ .

When the flow of powder is transported coaxially to the laser beam, all directions of movement of the substrate are in a plane perpendicular to the direction of powder flow, so a nozzle with a coaxial feed (figure 2b) are independent of the direction of motion. In this case, possible a creation of products with more complex geometry. The geometry of the gas powder jet depends not only on the design of the nozzle, but also on its geometry. The main influence on the performance and stability of the process using a coaxial nozzle are: the angle of convergence, the width of the constriction of jet, the uniformity of distribution of the powder relative to the axis of the laser beam. As a result of the research is the main factor determining the width of the gas powder jet at the outlet of nozzle, is the width of slot of the nozzle. The experimental data show that the jet has a normal distribution in the cross section at a distance of more than double the width of the nozzle (figure 3).

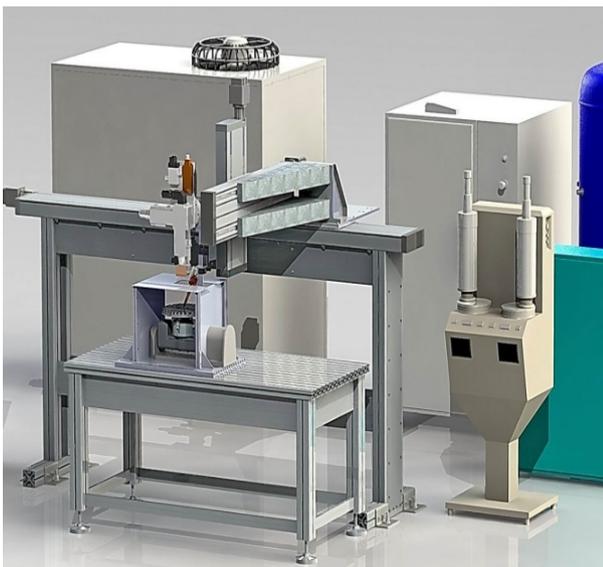


**Figure 3.** Dependence of the width of jet to the width of slot of nozzle, the size of particles of powder is 50-150  $\mu\text{m}$ .

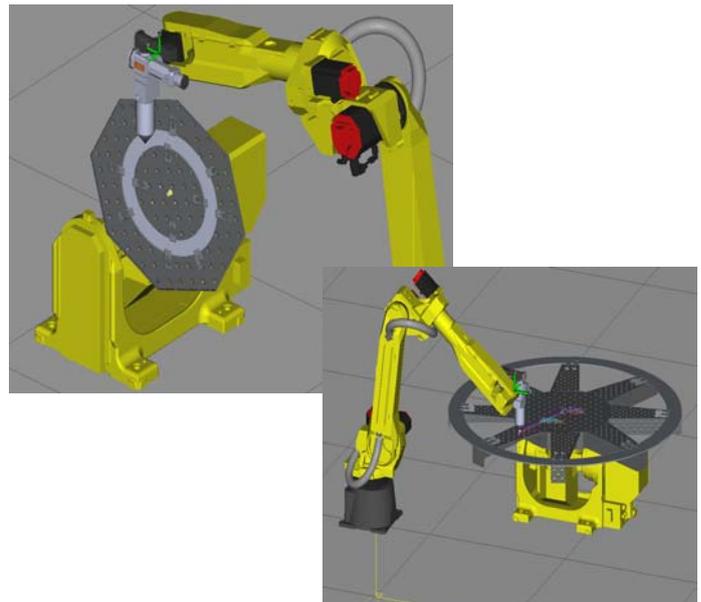
To implement the process possible to use the following series of technological equipment:

Setups that use linear drive (figure 4a) or robot (figure 4b) to move a work tool and a rotator located in the shielding chamber to control of movement of the substrate;

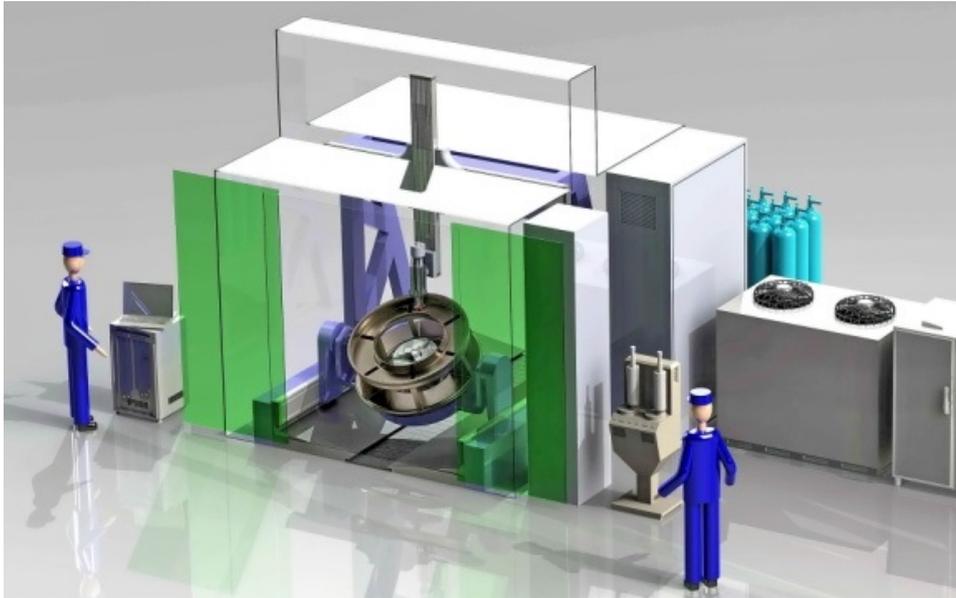
The equipment is made on the basis of CNC systems for machining, with the replacement of the working tool on a special for direct laser deposition and with the possibility of filling the working chamber with inert gas (figure 4c);



a)



b)



c)

**Figure 4.** Images of using machines for the process of high speed direct laser deposition of products.

The first two types are created by employees of Institute of laser and welding technologies SPbSPU for the research process high-speed direct laser deposition of products.

#### 4. Materials

Experimental research have been carried out using the metal powder of the base alloys: nickel, including heat resistant (Inconel 625), cobalt, including high strength (Stellite 6), chromium, iron, copper and titanium. The future plans are to include studies of process with powders based on aluminium alloys. The powders had a spherical shape of the particles. This is due, firstly, to the fact that such particles more compactly fit into a certain volume and secondly, to provide a “fluidity” of powder compositions in feed systems with minimal resistance. The original powder have been separated using a vibrating screen 30 GY in divided fractions by sifting of initial powder through a set of sieves with respective cell dimensions. The distribution of powder particles size have been controlled by using a laser analyzer of microparticles LASKA-1K. The choice of this fraction of the powder caused by the economic expediency of its application for the deposition of large products used in industries such as gas turbine engine building and aviation. The using of powder with smaller size of particle allows to obtain products with a smaller roughness of surface, but it increases the cost of the powders and causes difficulty in the formation of stable gas-powder jet of the weight of the flying particle. The material ratio can vary from 20 to 90% depending on the combination of parameters of cultivation. Examples of samples of deposition of products are presented in figure 5.



**Figure 5.** Samples of the deposition products:

- a) Fe alloy: EuTroloy 16316.04; b) Co alloy: EuTroloy 16006.04;  
 c) Ni alloy : EuTroloy 16496.04; d) Ni alloy (experimental alloy of ODC );  
 e) Ni alloy: EuTroloy 16625.04; f) Cu alloy: BronzeTec 19868 (80Cu-15Al-5Ni).

### Conclusion

The research found out, the technology of high-speed direct laser deposition of products able to replace the current technology of giving multiple increase productivity and save material. The product obtained by this method, do not need next isostatic pressing or heat treatment, in comparison with the technology of selective laser sintering (melting) or casting techniques with next thermal and mechanical treatment. However, this process may be combined with other technologies, further reducing production costs, reducing the time for fabrication, creating products that cannot be obtained by using only this method. During the research the opportunity to create the nozzles of different configurations, to form edges on rotary body and on products with complex profile, to create the objects of variable cross section and with a controlled thickness of wall in the range of from 0.6 to 3 mm and a roughness of surface of not more than 50  $\mu\text{m}$  were confirmed. In the case where this is insufficient to reduce of the roughness to about 10 times the possible use of laser radiation for surface melting of the walls of the deposition products. The dimensions of the resulting product are limited by the size of the shielding chamber.

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