Laser cladding technological machine. Investigation of efficiency of various nozzles design

R S Korsmik\textsuperscript{1}, G A Turichin\textsuperscript{1,2} and K D Babkin\textsuperscript{1}

\textsuperscript{1}Peter the Great Saint-Petersburg Polytechnic University, 195251, Saint-Petersburg, Russia
\textsuperscript{2}Saint-Petersburg State Marine Technical University, 190121, Saint-Petersburg, Russia

E-mail: r.korsmik@ltc.ru

Abstract. The paper shows the correlation between nozzle design and efficiency of laser cladding process. The nozzles developed by authors are characterized by uniform distribution of the powder in the jet transection. The stable formation of the cladding beads is achieved when the gas-powder jet focused below the processing surface.

1. Introduction
An integral part of increasing the life process of turbo-fan engines is their maintenance and repair. In particular, this applies the main and most expensive mass-use structure elements – working blades. The causes of their deterioration or breakage are vibrations, shocks, abrasive deterioration, high temperatures and other factors during operation [1]. The cladding processes are used for restoration of damaged turbine blades.

TIG [2, 3] and EB [4, 5] cladding technology does not provide the same quality as laser method [6]. Both wire [7] and powder [8] are used as filler material. In case of wire-filler, the whole amount of material transfers to the cladded track. It is unquestionable advantage of this type of filler material from the economic side of technology. However, the fact that all amount of wire should be melted in the action zone causes the number of technological difficulties during automation process. In view of this, filler wire fed manually and cladding duration of one blade could be up to 1 h [8]. In case of powder-filler, material transfers to cladded track partly. Amount of cladded powder depends on number of technological parameters of process and design of equipment, which influence to powder transportation and melting processes [9]. In the case of large areas cladding, it is advisable to use a laser beam scanning to increase the area of the melting zone. In this case, weight of cladded material could be up to 80 % of fed powder [10]. As applied to restoration cladding of turbine blades, scanning of laser beam is not expediently, because of narrow width of processing area (approximately 1 mm). In this way, there is an issue to increase amount of powder, which transfers to cladding, with help of better focusing ability of gas-powder jet. This paper shows powder transfer coefficient investigation in depending on nozzles design, which are working tool of laser cladding technological machines.

2. Methods, materials and equipment
Experimental research was done on laser cladding technological complex based on industrial robot LRM-200iD\_7L, Fanuc; laser irradiation source LK-700, IPG Photonics; laser head FLW D30, IPG
Photonics with removable cladding nozzles (table 1); powder feeder Oerlikon Metco Powder Feeder Twin 150 with track transection of metering disk of 5×0.6 mm².

Table 1. General geometrical investigating nozzles parameters.

| Nozzle     | Cone angle, deg | Gap between cones, mm |
|------------|-----------------|-----------------------|
| ILWT-N2    | 36.0            | 0.26                  |
| ILWT-N3    | 40.0            | 0.24                  |

Powder of Co-alloy EuTroLoy16006-04 (Stellite 6) Castolin Eutectic was used for experiments. The fracture grain size of powder is 20–53 and 50–150 μm. For calculating powder transfer coefficient was used formula:

\[ K = \frac{M}{TG} \]

where \( M \) – is powder mass, transferred through hole in container per time unit \( T \); \( G \) – nominal powder rate. Nominal powder rate was determined by weighting of powder, transferred to container in time unit \( T \). Experiments for measuring of powder transfer coefficient were done with use of laboratory stand, which models melting pools of various size. Stand consists of plate with holes of 0.8; 1.5; 2.0; 3.0; 4.0 mm diameter, which is parallel to nozzle edge, and container that is placed on the weighting-machine under the plate. Powder transfer coefficient was studied for each of holes with gap between nozzle edge and plate from 4 to 16 mm.

The series of cladding beads were done to actualize results of modeling experiment. The gap between nozzle edge and plate was from 6 to 15 mm. For the actual powder transfer coefficient were calculated duration of 50 layers. Cladding parameters: laser power – 300 W, beam diameter on the substrate – 0.8 mm, cladding speed – 20 mm/s.

3. Results and discussion

Nominal powder rate determined in result of experiment is 12.9 g/min. Results of measurement transferred powder mass through the holes shows that powder transfer coefficient decreases with decreasing of hole diameter. The figure 1(a), (b) shows depending powder transfer coefficient for nozzles “ILWT-N2” and “ILWT-N3”.

![Figure 1](image_url)
During the influence investigation of gap between nozzle edge and plate, was found a maximum value, which means about focus of gas-powder jet. The focus distance for nozzle “ILWT-N2” is 13 mm. With decreasing of hole diameter the curve inflection becomes more expressed. The focus distance of gas-powder jet for nozzle “ILWT-N3” is 11–12 mm from the bottom edge. The curve inflection is more expressed for diameters up to 2 mm. For hole diameter of 4 mm dependence character becomes more smooth. The powder transfer coefficient at least does not change with gap form 6 to 10 mm, and saves maximum value.

The powder transfer coefficients in the focuses of gas-powder jets were compared to determine efficiency of nozzles. Comparing curves are showed in figure 2.

As shown in diagram, the nozzle “ILWT-N3” provides higher powder transfer coefficient then nozzle “ILWT-N2”. In case of nozzle “ILWT-N3”, the powder transfer coefficient increases in 1.2–3 times for holes 1.5–4 mm in comparison with nozzle “ILWT-N2”. For hole diameter of 0.8 mm the powder transfer coefficient is 0.14 whereas nozzle “ILWT-N2” cannot focuses gas-powder jet to such size.

Investigation of powder fracture influence reveals that decreasing of grain size insignificantly increases powder transfer coefficient in 1.03–1.5 times.

For further cladding investigation were solved to use nozzle “ILWT-N3”, which provides higher powder transfer coefficient, and powder with fracture of 50–150 μm, which costs lower. In the results of cladding, 10 built-up “walls” were obtained. The width of each wall is 1.15 mm.

The height of walls is not equal. It changes from 5.03 to 15.83 mm. Obtained walls could be separated to two groups. The first one is walls with stable formation (the focus of gas-powder jet is below of substrate surface). The second group is walls with unstable formation (the focus of gas-powder jet is above of substrate surface) [11]. Maximum height of wall is achieved during cladding with gap between nozzle and substrate surface is 12 mm. The figure 3 shows dependence of cladded height and distance between nozzle edge and substrate surface.

Cladding duration of 50 layers is 75 s. It means that 16.13 g of powder was fed (powder rate is 12.9 g/min). Cladded mass is 4.18 g. In this way, actual powder transfer coefficient is 0.26.
4. Conclusions
Based on conducted experiments it can be seen, that various designs of cladding nozzles provide different values of powder transfer coefficient. The nozzle “ILWT-N3” has better focusing ability than the nozzle “ILWT-N2” and increases the material utilization during the processing of small areas.

The proposed modeling method makes it possible to compare the different nozzles without conducting cladding experiments. Comparing the powder transfer coefficient, measured after cladding the samples, with the powder transfer coefficient, measured after the experiments at the stand, which simulates melting pools of different diameters (figure 2), it can be seen that the results are practically the same.

Surfacing must be done at the distance between the nozzle edge and the cladding surface, which does not exceed the focal length of the gas-powder jet provided by the nozzle. Investigation have shown a monotonous increasing of the deposited height (due to increasing of powder transfer coefficient), up to the focus point of the gas-powder jet. When the focus point of gas-powder jet sets above of cladding surface, the powder transfer coefficient decreases because of the low and unstable concentration of particles in the jet. This leads to excessive losses of filler material and leaving from a stable condition of process.

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