Design and optimization of discrete powder nozzle for laser metal deposition

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Abstract. For design and optimization of discrete powder nozzle for laser metal deposition the experimental research was completed. Influence of powder jet geometry, of powder streams interaction and influence of shield gas at powder efficiency was investigated. The prototype of discrete powder nozzle was designed. Experimentally defined, that powder jet with inner diameter 1.4 mm and length 60 mm provide the highest powder efficiency for discrete powder nozzle. Interaction of gas-powder streams causes a decrease of powder efficiency. Shield gas using doesn’t affect powder efficiency of discrete powder nozzle.

Keywords. Additive manufacturing, laser metal deposition, powder nozzles, coaxial discrete nozzle, powder efficiency, interaction of powder stream.

Introduction
Direct metal deposition method is one of the most perspective additive manufacturing methods, which is rapidly evolving during last few years [1-4, 10]. The main idea of this technique as is follows: laser radiation falls on the substrate, which melts material and creates a molten pool. At the same time from the special instrument – nozzle – is supplied metallic powder in a molten pool. Powder melts under influence of laser radiation and mix with melt. After cooling the molten pool, on the surface of the substrate is formed deposited roller. Using this approach layer-by-layer, create a part of any type. This method is quite easy to implement and so this doesn’t require complex equipment and the finite costs wouldn’t be high. Also the laser metal deposition technique relatively productive that allows producing massive details sufficiently complicated geometry from wide range of the metals quite fast [5]. As it’s additive method so for creating a solid detail is required less material in compare with convenience methods and this detail requires modest post-processing. Therefore, the efficiency increasing and enhancement of a main instrument – nozzle – is important mission [6, 7]. The productivity of laser metal deposition process and wall forming quality depends by the quality and geometry of nozzle, this is especially important for high-sized parts production [8, 9]. This article has dedicated of investigation of the influence different technological parameters at powder efficiency. The inclination angle, mutual streams impact, the presence of shield gas, the offset distance and the inner tubes diameters was investigated because these parameters has a high affecting on the powder efficiency and, respectively, on the maximum performance.

Powder efficiency measurement method
Special stand imitating the laser metal deposition process was assembled for powder efficiency measurement. Schema of measurement process is represented in Figure 1.
Measurement process description, powder jet is placed coaxially over the diaphragm, on standoff distance. Further the powder is fed through the powder jet in the aperture of the diaphragm, which limits the powder flow. The diaphragm imitates a molten pool. On electric scales, under diaphragm is placed a beaker, there is collect all powder passed through the diaphragm. When a certain time has passed and powder feeding is stopped, then measure the mass of powder in the beaker. Further the mass of powder from the beaker compare with the mass of powder supplied by powder feeder. The relation of powder mass from beaker to powder mass supplied from powder feeder is called powder efficiency.

Powder rate is regulated by a powder feeder. The design of powder feeder, which was used for measurement, doesn’t allow setting the nominal powder rate by a specific number; is possible setting the value of the rotation speed of the disk transporting the powder only as a percentage. Therefore, the nominal rate of powder should be calculated. To do this set the value of rotation speed of the disk and the powder mass was measured without diaphragm.

Nominal powder rate is calculated by formula (1):

$$R_{nom} = \frac{m_{pow}}{t \times v}$$

(1)

where \(m_{pow}\) – powder mass, g; \(t\) – measurement time, s; \(v\) – value of rotation speed of disc, %.

When nominal powder rate known, powder efficiency can be calculated by formula 2:

$$K_{pe} = \frac{m_{pow}}{R_{nom} \times t}$$

(2)

\(K_{pe}\) – nominal powder rate, g/s; \(mpow\) – powder mass from beaker, g; \(t\) – measurement time, s.

**Experimental research.**

*The geometry of powder jets*

The powder distribution at the end of nozzle and as result powder efficiency depends by geometry of powder jets. Analysis of existing discrete powder nozzles showed that mainly used powders jets with inner diameter 1.4-1.6 mm and length 50-60 mm. Existing discrete powder nozzles provide max. powder efficiency at 95% at track widths of 5 mm. Measurement results will be compared with this value. Objective of this research: achieve powder efficiency of at least 70% at track widths of 2 mm.
For determining the optimal geometry of powder jets, measured powder efficiency for powder jets with inner diameter 2 mm, 1.6 mm, 1.4 mm, 1.2 mm and length 80 mm, 60 mm, 50 mm, 40 mm for each inner diameter. Powder efficiency measured on standoff distance 12 mm, 16 mm, 20 mm, 25 mm.

Technological parameters of measurements: powder fraction 50-150 µm, powder rate 15.5 g/min, transporting gas rate 4 l/min, diameter of diaphragm aperture 2 mm, measurement time 3 min. Results of measurement represented in Fig.s 2-5.

**Figure 2.** Dependence of powder efficiency for length of powder jet with inner diameter 1.6 mm

The measurement result for powder jets with inner diameter 2 mm showed low values of powder efficiency. The maximum possible value of powder efficiency doesn’t exceed 65% when using powder jet with length 50 mm.

The measurements of powder efficiency for powder jets with inner diameter 1.6 mm also showed low values of powder efficiency. The maximum possible value of powder efficiency doesn’t exceed 67% when using powder jet with length 80 mm.

**Figure 3.** Dependence of powder efficiency for length of powder jet with inner diameter 1.6 mm
The measurements of powder efficiency for powder jets with inner diameter 1.4 mm also showed high values of powder efficiency. As seen in Fig. 4, the maximum possible values of powder efficiency exceed 82% when using powder jet with length 60 mm.

The measurements of powder efficiency for powder jets with inner diameter 1.2 mm also showed low values of powder efficiency both like first and second measurements. The maximum possible values of powder efficiency doesn’t exceed 68% when using powder jet with length 80 mm and doesn’t exceed 40% at maximum standoff distance, when using powder jet with length 60 mm.

All measurement data showed that powder jet with inner diameter 1.4 mm and length 60 mm provide highest powder efficiency.

**Figure 4.** Dependence of powder efficiency for length of powder jet with inner diameter 1.4 mm

**Figure 5.** Dependence of powder efficiency for length of powder jet with inner diameter 1.2 mm

**Powder streams interaction**

Design of discrete powder nozzle is formed in mixing of tree powder streams in one point. It will provoke interaction of powder streams and powder efficiency will decrease, compared with one powder jet. For determining interaction of powder stream the next measurements were done:

1) Interaction of 3 powder streams
2) Interaction of 2 powder streams and 1 gas stream
3) Interaction of 1 powder streams and 2 gas stream
4) Feeding powder through 1 powder jet (1 powder stream)
5) Technological parameters of measurements: powder rate 15.5 g/min, standoff distance 12 mm, powder jet with inner diameter 1.4 mm and length 60 mm, transporting gas rate 4 l/min, diameter of diaphragm aperture 2 mm, measurement time 3 min. Measurements results is represents in Fig. 6.

Measurement results showed decrease of powder efficiency on 4% for interaction of two gas streams with one powder stream relatively to powder efficiency for one powder stream. Also the results showed decrease of powder efficiency on 10% for two powder streams and one gas streams, decrease of powder efficiency on 12% for interaction of three powder streams. These data are explained by the fact that when powder feeding through additional powder jets, the number of gas-powder streams interacted with other gas-powder streams is increased, as result powder efficiency is decreased. In measurement No. 3 seen that one gas-powder stream is interacted with two gas streams, as result powder efficiency is decreased on 4%. In measurement No. 2 seen that every of gas-powder streams is interacted with two other streams. Powder efficiency is decreased for every gas-powder stream so the total powder efficiency is decreased more than in measurement No. 3. In measurement No. 1 powder efficiency is decreased more than in measurement No. 2 and No. 3, by same reason.

Influence of shield gas on the powder streams.
In laser metal deposition, the shield gas used to protect molten pool from interaction with air. That’s need to limit interaction of molten metal with air, because fragile compounds are formed in the metal structure when molten metal interact with oxygen and nitrogen, as result the durability of the final product decreases. The shield gas is the stream of inert gas, argon for example, which displace the air from molten pool. Argon is fed coaxially in point where powder streams are mixed, as result powder efficiency may change. The refore is necessary to determine influence degree of shield gas on powder efficiency, for it powder efficiency was measured. Measurements results is represents in Fig. 7.
Fig. 7. Influence of shield gas on the powder efficiency

Technological parameters of measurements: powder rate 15.5 g/min, standoff distance 12 mm, powder jet with inner diameter 1.4 mm and length 60 mm, transporting gas rate 4 l/min, diameter of diaphragm aperture 2 mm, measurement time 3 min. The measurements sowed equivalent results, so shield gas doesn’t affect powder efficiency.

Conclusion
- Experimentally defined, that powder jet with inner diameter 1.4 mm and length 60 mm provide the highest powder efficiency for discrete powder nozzle.
- Interaction of gas-powder streams causes a decrease of powder efficiency.
- Shield gas using doesn’t affect powder efficiency of discrete powder nozzle.

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