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## INVESTIGATION OF THE SPEED OF MOVEMENT OF POWDER PARTICLES OF COLD GAS DYNAMIC SPRAYING

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*The article shows the results of the study of the velocity of the sprayed powder particles on the example of cold gas-dynamic spraying of copper powder C01-11. Features and advantages of gas-dynamic spraying before other gas-thermal coating methods are given. The importance of the speed regime of coating and its influence on the formation of the coating is analyzed. A computational experimental method for determining the velocity of sprayed particles is proposed, as well as an experimental setup with the help of which it is possible to obtain objective data on the velocity regime of cold gas-dynamic coating. The design of the applied gas-dynamic spraying device is shown, which contains an electric heater of the compressed air flow and an accelerator of the heated compressed air into which the sprayed metal powder is driven due to the ejection effect. An experimental setup was used for the study, which contained two rotating disks mounted at a distance of 20 mm from each other on the shaft of a high-speed electric motor, with holes in the upper disk through which spraying occurs on the surface of the lower disk. Due to the fact that the disks with the spraying process rotate at a speed of 10587 rpm is the displacement of the sputtering figure on the lower disk relative to the projection of the hole of the upper disk on the lower disk. The magnitude of this displacement is calculated by the velocity of the particles of the sprayed powder, according to the above method. The parameters that are taken into account when calculating the speed of the spray particles of the powder is the diameter of the nozzle of the spray device 5 mm. The distance from the nozzle cut to the upper disk is 10 mm. The distance from the nozzle cut to the lower disk is 32 mm. The distance between the disks  $a = 22$  mm. The radius on which the nozzle of the spray device is installed is 90 mm.*

*As a result of the experiments, it was found that when spraying copper powder C01-11 at a temperature of 20 °C, the spraying speed is 232.2 m / s, which does not provide conditions for coating, and at elevated temperatures to 285 °C quality coating was formed. The spraying speed was from 302.7 to 359.2 m / s for critical sections of 2.5 and 3.01 mm<sup>2</sup>, and the spraying area at higher speeds was approximately 20% higher than at lower speeds. This makes it possible for researchers to determine the velocity modes of spraying and, accordingly, to more accurately assign the optimal technological parameters to achieve the highest quality results of creating functional coatings.*

**Key words:** cold gas-dynamic coating, spray rate.

**F. 6. Fig. 7. Table 1. Ref. 8.**

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### 1. Introduction

Cold gas-dynamic spraying (CGDS) is one of the latest rapidly evolving technologies [1, 4, 5, 6, 7, 8]. In the process of CGDS powder particles of metals, polymers, ceramics, with a characteristic size of 10-150  $\mu\text{m}$  are accelerated in the high-speed gas flow to speeds of 250-1200 m / s and when hitting an obstacle are fixed on its surface without phase transitions forming a continuous coating. The absence of high temperatures significantly expands the possibilities of coating methods of different powder materials and provides the method of CGDS, in comparison with existing gas-thermal methods, significant advantages:

- allows to use for spraying powders with a size less than 30-50 microns, including ultrafine, which leads to improved coating quality - increases its density, reduces the volume of microcavities, the structure becomes more homogeneous, it is possible to reduce the thickness of the coating;

- there is no significant heating of particles and related processes of high-temperature oxidation and phase transitions, which makes it possible to obtain coatings with properties close to the powder material, as well as composite coatings from a mixture of powders that differ significantly in physical and mechanical properties;

- there is no significant thermal effect on the surface of the product, which makes it possible to apply



a coating on substrates of non-heat-resistant materials;

- relative simplicity of technical implementation and improvement of work safety due to low temperature of the spraying process, as well as the absence of flammable and explosive gases.

In addition, it is possible to improve the performance of the surface layer of the part by applying special metal, polymer and composite coatings on its surface.

## 2. Problem formulation

An important factor influencing the process of creating coatings is the speed with which the sprayed powder particles fall on the surface of the sprayed part. The quality and characteristics of the applied coating largely depend on it. But you can directly measure the velocity of a microscopic powder particle only using expensive optoelectronic equipment [1, 4, 5], or determine the speed using analytical methods that have a number of assumptions [2] and, accordingly, the calculation results may have significant deviations from the actual flow rate of powder particles in the moment of collision with an obstacle.

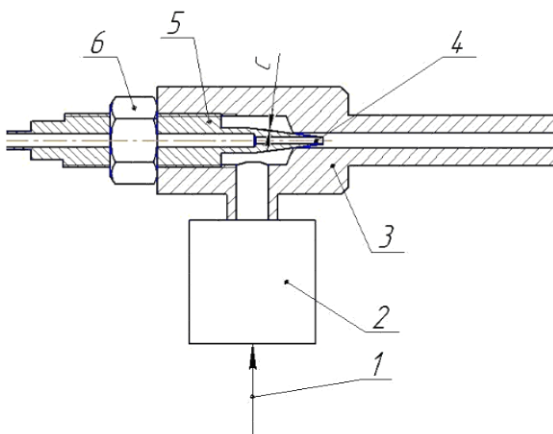
## 3. A purpose of work

The aim of the work is to develop a simple computational experimental method that will accurately determine the speed of the spray particles in the process of gas-dynamic spraying.

## 4. Results of research

For spraying used an experimental device for gas-dynamic spraying of functional coatings, the schematic diagram of which is shown in Figure 1. The device consists of a nozzle 3 having a cylindrical hole of constant diameter, in which the left side is nozzle 5. Nozzle 5 has an axial channel 4 for feeding the sprayed powder material and the outer conical part, which in connection with the nozzle opening forms an annular gap C, which is the mouth of the nozzle and its critical section. The critical section is the area of the nozzle mouth with the minimum area of the annular gap through which the compressed air passes. Moving the nozzle 5 along the axis of the nozzle 3 allows you to adjust the gap C (critical section), which allows you to adjust the pressure and flow rate of the working gas and adjust the parameters and quality of the sprayed coating. Passing through the critical section, the gas flow rate accelerates and its pressure drops to values less than atmospheric. That is, the effect of ejection is created due to which the sprayed material is absorbed into the nozzle of the installation.

Another feature of the developed design is that the air flow passing through the nozzle of the new design moves from the periphery to the axis of the nozzle. This helps to keep the powder particles mainly on the axis of the nozzle, which will significantly reduce the likelihood of their collision with the surfaces of the nozzle hole and, accordingly, will reduce the wear of these surfaces.



*Fig. 1. Schematic diagram of the device for gas-dynamic application of functional coatings:*

*1 – compressed gas supply, 2 – gas heater,  
3 – nozzle, 4 – powder supply channel.  
5 – a nozzle, 6 – a lock nut*

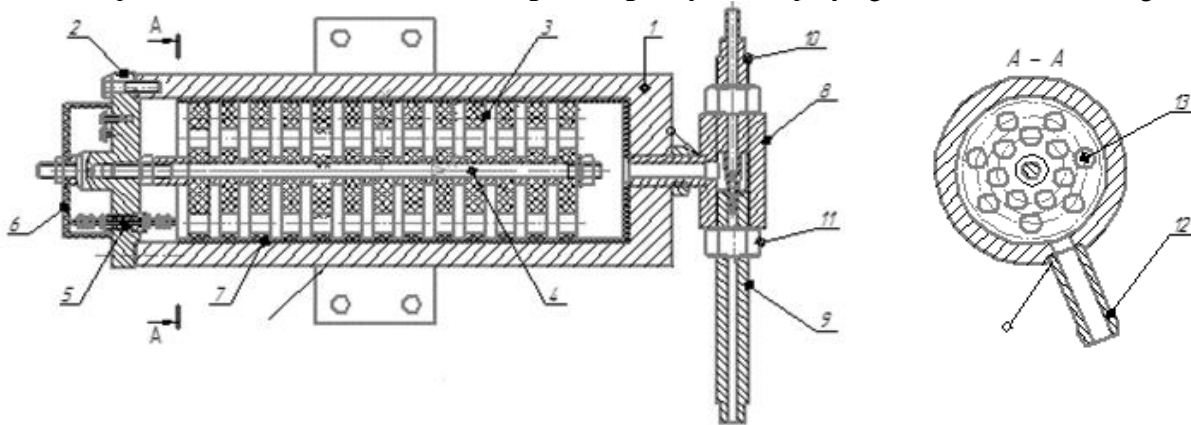


*Fig 2. Gas-dynamic spraying device,  
general view*

To implement the process of cold gas-dynamic spraying in created special equipment shown in Fig. 2.



Gas-dynamic spraying device [3] consists of two main components: a compressed air heater and a heated compressed air accelerator. The drawing of the gas-dynamic spraying device is shown in Figure 3.



**Fig. 3. The structure of the gas-dynamic spraying device**

The spray device consists of a housing 1, cover 2, ceramic disks 3 with holes 13, disk holder 4, electrical contacts 5, insulating cover 6, thermal insulator housing 7, supersonic nozzle 8, barrel 9, cone 10, nut 11, compressed nozzle air 12.

As the spray material used copper powder C01-11 shown in Figure 4.



**Fig. 4. Copper powder.**

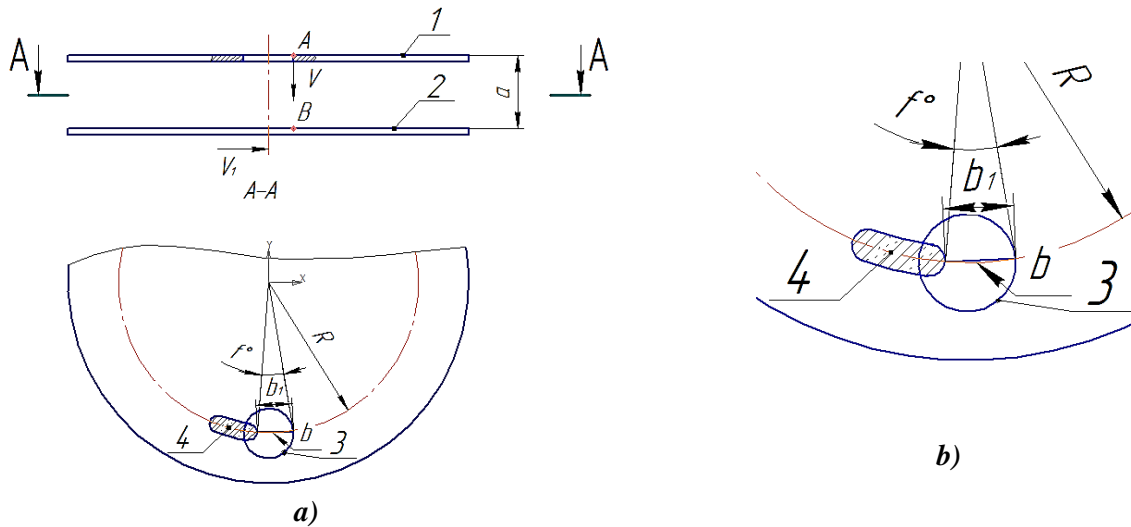


**Fig. 5. General view of the installation for determining the flow rate of powder particles:**  
**1 – electric motor, 2 – upper disk, 3 – lower disk,**  
**4 – nozzle of the CGDS device, 5 – holes in the upper disk,**  
**6 – projection of the upper hole 5 on the lower disk 3,**  
**7 – spray layer on the lower disk.**

An experimental setup was developed to study the flow rate of powder particles (Fig. 5). This installation consists of a high-speed electric motor, on the shaft of which two disks are fixed. Symmetrically arranged holes with a diameter of 20 mm are made on the upper disk.

The spraying process was as follows. The nozzle 4 of the spray device is placed on the axis of the hole 5 of the upper disk. We turn on the electric motor 1 of the installation, which accelerates the rotation of the disks 2 and 3 to certain values, the spray installation is displayed on certain spray modes and the powder material is fed into the nozzle 4 of the spray device. There is a process of creating a coating layer. Part of the powder enters the hole in the upper disk and reaches the surface of the lower disk and a spray layer 7 is formed on the lower disk 3. Due to the fact that the disks rotate, there is a shift of the spray layer relative to the projection 6 of the hole in the upper disk. The magnitude of this shift determines the flow rate of the sprayed powder.

**Method of calculation.** To determine the velocity, we developed a calculation scheme, shown in Figure 6, and determine the mathematical dependences by which we can calculate the flow velocity of particles at a distance (a).



**Figure 6. Calculation scheme for determining the flow rate of spray particles:**

*a* – scheme of installation in the front plane and section AA, *b* – additional enlarged view of section AA, 1 – upper disk, 2 – lower disk, 3 – projection of hole A on the lower disk, 4 – spray layer on the lower disk. B is the projection of the point of hole A on the lower disk. V – Flow rate of powder particles.  $V_1$  is the velocity of point B, *b* is the segment of the arc along which point B moved,  $b_1$  is the chord connecting the end points of the arc *b*, *R* is the radius of point B (coincides with the axis of the nozzle of the spray device), *f* is the angle of the sector connects the endpoints of the arc *b*, and *a* – the distance between the surfaces of the disks 1 and 2.

The powder particle will fly the way  $a = Vt$ , where *t* – the time of movement of the powder particles at a distance *a*. Then  $t = a/V$ . The disks will go the way of this time  $b = V_1t$ , where  $t = b/V_1$ .

Then write down the equality  $a/V = b/V_1$ , whence the velocity of the powder particle  $V = (aV_1)/b$ . The arc *b* is part of a circle of radius *R*. The length of a circle of radius *R* is  $C = 2\pi R$

From the known speed per minute *n*, we can calculate the speed  $V_1$  of point B

$$V_1 = Cn \quad (1)$$

Where

$$V = (a2\pi Rn)/b \quad (2)$$

By the cosine theorem we determine the angle *f*.

$$f = \arccos(2R^2 - (b_1)^2)/2R^2 \quad (3)$$

The length of the arc *b* passing the point B for time *t* is calculated by the proportion

$$\frac{2\pi R}{360} - b \quad (4)$$

Where

$$b = f2\pi R/360 = (\arccos((2R^2 - (b_1)^2)/2R^2)2\pi R)/360 \quad (5)$$

If *n* is rpm, and the dimensions is meters, we obtain

$$V = (an)/(\arccos((2R^2 - (b_1)^2)/2R^2)/360) \text{ m/min.} \quad (6)$$

According to the above method and the results of spraying (Fig. 7) measure the amount of displacement of the coating layer relative to the projection of the upper hole on the lower disk. It for different spraying modes is  $b_1 = 9.54 \text{ mm}; 7.25 \text{ mm}; 6.11 \text{ mm};$

The diameter of the nozzle hole of the spray device is 5 mm. The distance from the nozzle cut to the upper disk is 10 mm. The distance from the nozzle cut to the lower disk is 32 mm. The distance between the disks  $a = 22 \text{ mm}.$

Based on the results obtained, calculate the velocity of the powder particles, and the results are listed in table 1.

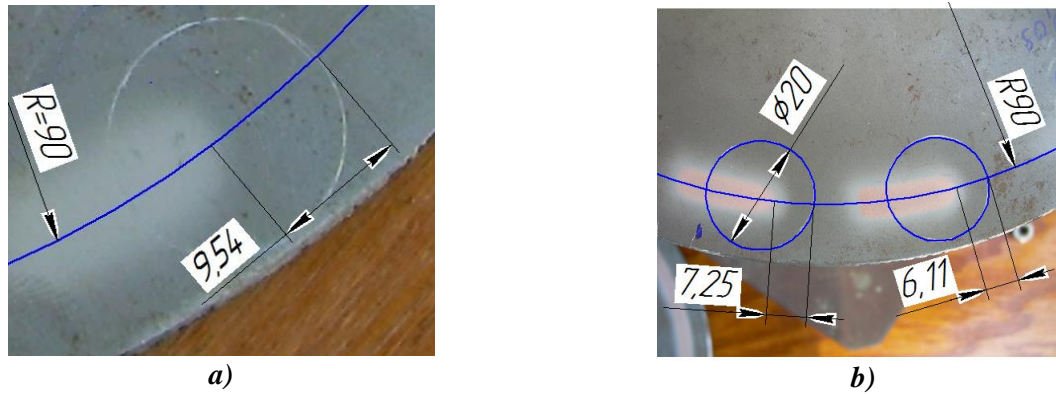


Fig. 7. Geometric parameters of the spraying layer: a - spraying at a temperature of 20°C compressed air (coating is not formed), b - spraying layer from right to left: the first layer, compressed air temperature 285 °C, critical cross section 3.01 mm<sup>2</sup>, the second layer c compressed air temperature 285 °C, critical nozzle cross section 2.5 mm<sup>2</sup>. Air pressure for all experiments is 0.57 MPa.

Table 1

*Velocity of the powder particles*

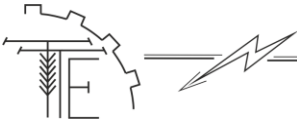
a, m	n, min <sup>-1</sup>	b <sub>1</sub> m	R m	Critical nozzle cross section mm <sup>2</sup>	Air temperature	Pressure air MPa	V m/s
0,022	10587	0,00954	0,09	3,01	20 °C	0,57	232,2
0,022	10587	0,00725	0,09	2,5	285 °C	0,57	302,7
0,022	10587	0,00611	0,09	3,01	285 °C	0,57	359,2

**4. Conclusions**

A computational experimental method for determining the velocity of the sprayed powder has been developed, which makes it possible to accurately determine the velocity of the powder using simple equipment and a simple calculation method. This makes it possible for researchers to determine the velocity modes of spraying and, accordingly, to more accurately assign the optimal technological parameters to achieve the highest quality results of creating functional coatings. For example, it was found that when spraying copper powder at a temperature of 20 °C, the spraying speed is 232.2 m / s, which does not provide the conditions for coating, and when the temperature rises to 285 °C, a quality coating is formed. The sputtering speed ranged from 302.7 to 359.2 m / s for critical sections of 2.5 and 3.01 mm<sup>2</sup>, and the sputtering area at higher speeds was approximately 20% higher than at lower speeds.

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### ИССЛЕДОВАНИЕ СКОРОСТИ ДВИЖЕНИЯ ПОРОШКОВИХ ЧАСТИЦ ХОЛОДНОГО ГАЗОДИНАМИЧЕСКОГО НАПЫЛЕНИЯ

В статье приведены результаты исследования скорости полета частиц напыляемого порошка с применением холодного газодинамического напыления порошка С01-11 на основе меди. Показаны особенности и преимущества газодинамического напыления перед другими способами газотермического нанесения покрытий. Проанализированы разные скоростные режимы напыления и показано их влияние на формирование покрытия. Разработан расчетно экспериментальный метод для определения скорости напыляемых частиц, спомощью экспериментальной установки что позволяет получить объективные данные о скоростном режиме создания покрытий холодным газодинамическим напылением. Показана конструкция примененного устройства для газодинамического напыления, содержащего электронагреватель сжатого воздуха, и ускоритель сжатого воздуха в который с помощью эффекта эжекции водится напыляемый металлический порошок. В ходе исследования применялась экспериментальная установка которая содержит два вращающихся диска установленных на расстоянии 20 мм друг от друга на валу высокоскоростного электродвигателя, причем в верхнем диске сделано отверстия, через которые происходит напыление на поверхность нижнего диска. С учетом того, что диски с процессе напыления вращаются со скоростью 10587 об/мин происходит смещение фигуры напыления на нижнем диске относительно отверстия верхнего диска и его проекции на нижний диск. По величине этого смещения находится скорость движения частиц напыляемого порошка, по разработанной методике. Параметры которые принимаются во внимание при расчете скорости движения напыляемых частиц порошка это диаметр канала сопла газодинамического устройства 5 мм. Расстояние от сопла до верхнего диска 10 мм. Расстояние от сопла до нижнего диска 32 мм. Расстояние между дисками  $a = 22$  мм. Радиус на котором смонтировано сопло устройства для напыления относительно оси вала электродвигателя, это 90 мм.

В результате проведенных опытов получено, что при напылении медного порошка С01-11 при температуре 20 °С рассчитанная скорость напыления составляет 232,2 м/с., что не обеспечивает условий образования покрытия, а при повышении температуры до 285 °С покрытие образовалось. Скорость напыления, в этом случае, составляла от 302,7 до 359,2 м/с для критических сечений сопла 2,5 и 3,01 мм<sup>2</sup>, а площадь напыления при большей скорости оказалась примерно на 20% больше, чем при меньшей скорости. Предложенная методика позволяет определять скоростные режимы напыления и соответственно более точно назначать оптимальные параметры технологии нанесения функциональных покрытий для достижения наиболее качественных результатов.

**Ключевые слова:** холодное газодинамическое нанесение покрытия, скорость напыления

**Ф. 6. Рис. 7. Табл. 1. Лит. 8.**

### ДОСЛІДЖЕННЯ ШВИДКОСТІ РУХУ ПОРОШКОВИХ ЧАСТИНОК ХОЛОДНОГО ГАЗОДИНАМІЧНОГО НАПИЛЕННЯ

У статті наведені результати дослідження швидкості польоту частинок напилюваного порошку із застосуванням холодного газодинамічного напилення порошку С01-11 на основі міді. Показано особливості та переваги газодинамічного напилення перед іншими способами газотермического нанесення покриттів. Проаналізовані різні швидкісні режими напилення і показано їх вплив на формування покриття. Розроблено розрахунково експериментальний метод для визначення швидкості напилюваних частинок,

за допомогою експериментальної установки який дозволяє отримати об'єктивні дані про швидкісний режим створення покриттів холодним газодинамічним напиленням. Показана конструкція застосованого пристрою для газодинамічного напилення, що містить електронагрівач стисненого повітря, і прискорювач стисненого повітря в який за допомогою ефекту ежекції водиться напилюваний металевий порошок. В ході дослідження застосовувалася експериментальна установка



яка містить два обертових диска встановлених на відстані 20 мм один від одного на валу високошвидкісного електродвигуна, причому у верхньому диску зроблено отвори, через які відбувається напилення на поверхню нижнього диска. З урахуванням того, що диски з процесі напилення обертаються зі швидкістю 10587 об/хв відбувається зміщення фігури напилення на нижньому диску щодо отворів верхнього диска і їх проєкцій на нижній диск. За величиною цього зміщення знаходиться швидкість руху частинок напилюваного порошку, по розробленій методиці. Параметри які беруться до уваги при розрахунку швидкості руху напилюваних частинок порошку це діаметр каналу сопла газодинамічного пристрою 5 мм. Відстань від сопла до верхнього диска 10 мм. Відстань від сопла до нижнього диска 32 мм. Відстань між дисками  $a = 22$  мм. Радіус на якому змонтовано сопло пристрою для напилення щодо осі вала електродвигуна, це 90 мм.

В результаті проведених дослідів показано, що при напиленні мідного порошку С01-11 при температурі 20 °С розрахована швидкість напилення становить 232,2 м/с, що не забезпечує умов утворення покриття, а при підвищенні температури до 285 °С покриття утворилося. Швидкість напилювання, в цьому випадку, становила від 302,7 до 359,2 м/с для критичних перерізів сопла 2,5 і 3,01 мм<sup>2</sup>, а площа напилення при більшій швидкості виявилася приблизно на 20% більше, ніж при меншій швидкості. Запропонована методика дозволяє визначати швидкісні режими напилення і відповідно більш точно призначати оптимальні параметри технології нанесення функціональних покриттів для досягнення найбільш якісних результатів.

**Ключові слова:** холодне газодинамічне нанесення покриття, швидкість напилення.

**Ф. 6. Рис. 7. Табл. 1. Літ. 8.**

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