Development of plasma technology for metal powders used in additive technologies

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Abstract. The article describes the main characteristics of plasma technology designed for the production of metal powders, such as voltage, current, plasma-forming gas flow rate, plasma flow temperature. Based on experimental data and theoretical calculations, mathematical models are constructed to refine the defining characteristics, as well as to visualize the process. The mathematical model contains a spray chamber, an electrode rotation mechanism, a gas mixture supply unit, a plasma heating source, and a water cooling system for the chamber walls. The method of a rotating electrode with plasma heating (PREP) was used.

1. Introduction
Since the beginning of the 21st century, in the developed countries of the world, many technology companies have begun to switch to more environmentally friendly and economical production. One of these areas, including these two aspects, is additive technology. Thanks to the layer-by-layer build-up of the part, the technology consumes the minimum required amount of material. However, despite all its advantages, there are a number of difficulties for the creation of this technology and its advancement in the future, which will need to be solved by current engineers and scientists. Conventionally, equipment for 3D printing can be divided into 3 components: this is what a 3D printer (iron) consists of; software (software) and consumables (metal powder, ceramic powder, plastic wire, etc.).[1-3]

Based on these needs, employees of the higher school of electric power systems showed interest in studying this problem and solving this problem, namely in creating a method for the production of metal powders. We have already started from our experience with similar materials and technologies: the deposition of metal coatings on the surface [1] and the spheroidization of powders in a plasma stream [2]. To solve this problem, the concept was adopted of creating a multi-jet direct-acting plasma installation.

2. Materials and methods
One of the existing methods for producing metal powders is the PREP technology, which consists in heating an indirect plasma arc of a rotating atomized electrode in a chamber filled with an inert gas mixture.[4] To calculate such a complex set of tasks and make changes to an existing installation, we used a number of software packages for modeling physicochemical problems, such as Comsol Multiphysics and Mathcad. All work can be divided into several subtasks:

- calculation and selection of a gas mixture and plasma-forming gas;
- calculation of power and heat loss in a plasma installation;
- creation of a model of a multi-jet plasma installation;
• simulation of a molten metal billet under the influence of a plasma arc of direct action;
• production and cooling of metal particles[5-6].

3. Results and discussion

To calculate the composition and transport properties of the gas mixture, we used, to a first approximation, the properties of argon and helium. To compile a system of equations describing the equilibrium in a medium, the following laws are used: the first one is based on the law of acting masses, and the second is based on finding the minimum thermodynamic potential of the system.

For charged components, the law of mass action is expressed by the Saha law[7-8]:

\[
\frac{n_e n_i}{n_a} = \frac{g_e Z_i(T)}{Z_a(T)} \left( \frac{2\pi m_e kT}{h^2} \right)^{3/2} \exp \left( -\frac{E_{ioniz}}{kT} \right)
\]

(1)

It is necessary to add the Dalton law to the systems of equations of thermodynamic equilibrium:

\[
\sum_{i=1}^{m} p_i = p
\]

(2)

Figure 1. Graph comparing the distribution of the specific heat of a plasma Ar + (He-10%), pure Ar and pure He.

Plasma properties such as \( \rho \) density and average heat capacity obtained using the calculation data will be used in the future to calculate the mathematical model.

• heat capacity at constant pressure \( c_p = \frac{dh_{nt}}{dT} \), (Figure 1).

• plasma density \( \rho = \sum_i m_i n_i = \frac{1}{N_A} \sum_i M_i n_i \), (Figure 2).
Figure 2. Graph comparing the distribution of the density of a plasma Ar + (He-10%), pure Ar and pure He.

The calculation of the plasma flow power is calculated based on the methods of heat transfer from the plasma torch to the molten part[9]:

- Joule heating $Q_D = \int_{t_1}^{t_2} RI^2 \, dt$
- Convective heating $Q_{conv} = q \cdot S \cdot St$
- Conductive heat transfer $Q_{cond} = \lambda \cdot \left( \frac{T_{ai}-T_{boil}}{\Delta z} \right) \cdot S_{spot}$
- Electronic component of arc power $Q_e = I \cdot \left( \frac{3}{2} \cdot k \cdot T_{e} \cdot \frac{1}{e} + e \varphi + \Delta U \right)$

The total received power is used to simulate the melting of a metal billet under the influence of a plasma stream. The results of this model are presented in the article[10].

As a result, we obtain an axisymmetric model of the plasma torch, to complete which we introduce the following equations: the equation of motion for the laminar flow, the continuity equation, the heat balance equation, the Maxwell system of equations.

\begin{align}
\rho \frac{\partial u}{\partial t} + \rho (u \cdot \nabla) u = & \nabla[-p I + \mu (\nabla u + (\nabla u)^T)] + \frac{Re(I \cdot B)}{2} \\
\rho \nabla (u) = & 0 \\
\rho C_p \frac{\partial T}{\partial t} + \rho C_p u \nabla T + \nabla(-k \nabla T) = & \frac{\partial}{\partial T} \left( \frac{5k_B T}{2q} \right) \cdot (\nabla T \cdot J) + E \cdot J + Q_{rad} \\
\nabla \times H = & J \\
\nabla \times A = & B
\end{align}
\[ J = \sigma E + \frac{\partial P}{\partial t} + J_e \]  

(8)

\[ E = -\nabla V \]  

(9)

Below is the simulation result of the plasma torch after 0.3 seconds. As can be seen from Figure 3, the plasma jet has a sufficient temperature, and the calculated power can melt the rotating electrode to further obtain a metal powder.

Figure 3. Physical model of the plasma system through \( t = 0.5 \)s, \( G=0.5 \)g/s.

Figure 4. Temperature distribution in a plasma arc and a metal workpiece \( t = 0.5 \)s, \( G=0.5 \)g/s.

The data obtained, in the course of mathematical modeling, made it possible to conduct an experiment in the laboratory of the Polytechnic University and measure the necessary values to continue work in this direction and solve the last subproblem, announced at the beginning of our article. rate, the less amount of eutectoid is formed.
Figure 5. The experiment with two plasmatrons, G=0.5g/s.

4. Conclusion
During the work, the water passing through the sprayed part was colorimetric, with the help of which it was confirmed that the required amount of heat was transferred to the workpiece, various plasma torch operation modes were checked, where the gas flow rate changed from 0.3 g / s to 1.5 g / s. It was noted that arc ignition is much easier with a small gas flow rate, and after establishing stable arc burning, the plasma gas flow rate can be increased. Future plans include the creation of a model of a gas chamber for calculating the cooling of metal particles and the trajectory of movement, as well as the continuation of the creation of the installation and conducting experiments.

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