The effect of the external acoustic waves on the plasma torch jet

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Abstract. Numerical experiments on the effect of the external acoustic waves on the plasma torch jet have been performed. The formation of a turbulent plasma torch jet upon application of an external acoustic waves is demonstrated.

1. Introduction

The effectiveness of plasma coating and their quality depend on the properties of materials and the main parameters of the plasma flow. Therefore, the main technological problem in the development of various plasma torch designs for coating is to obtain the optimal parameters of the plasma flow. Modes of plasma torch must ensure the effectiveness of the process, the coating quality and high endurance of the main plasma torch elements [1-4]. One of the important problems in coating is finding ways to control the plasma jet. With the development of plasma coating technology, various methods have been developed to control the characteristics of the plasma jet. In the present paper, the proposed development of a method for controlling the parameters of a plasma jet using an external acoustic waves [5]. The results of numerical experiments are given, it is shown that the application of external acoustic waves leads to the turbulence of the plasma jet.

2. Problem definition and solution method

When the gas dynamic interaction between the plasma jet and the particle, there is a strong temperature gradient at the surface of the particle, is known as Thermal Boundary layer. The thickness of the thermal boundary layer exceeds the thickness of the dynamic boundary layer. The thickness of the boundary layer and type of the plasma flow has a significant influence on the heat exchange between body and environment. In the case of a laminar plasma flow, heat exchange occurs predominantly due to the mechanism of thermal conductivity. The thermal conductivity of air plasma does not exceed 6 W/(m·K), therefore the thermal boundary layer is a significant thermal resistance.

In the transition from laminar to turbulent flow, the thermal resistance value is reduced by mixing the medium inside the boundary layer. It is effective for coating. This is confirmed by the following simple analysis. The coefficient of thermal diffusivity is defined as follows:

\[ \alpha = \frac{Nu \lambda}{2R}, \]
The Nusselt number for laminar and turbulent flow is determined, respectively:

\[
Nu = 2 + 0.5 \text{Re}^{0.5} Pr \left( \frac{\rho_l^{\infty}}{\rho_g^{\infty}} \eta_g^{\infty} \right)^{0.2}
\]  
(2)

\[
Nu_{|\text{turb}} = \frac{0.037 \left( \frac{\text{Re}}{\epsilon} \right)^{0.8} Pr^{0.33}}{1 + 2.443 \left( \frac{\text{Re}}{\epsilon} \right)^{-0.1} \left( Pr^{2/3} - 1 \right)}
\]  
(3)

Expressions (1) and (2) show that more intense heating is observed in the case of turbulent flow. On the other hand, this effect may be negative for electrodes and other internal parts of plasma torch. Erosion and premature wear will reduce the service life of the plasma torch. Therefore, when applying coatings, it is necessary to turbulize the plasma jet at the exit of the plasma torch nozzle. Therefore, when applying coatings, it is necessary to turbulize the plasma jet at the exit of the plasma torch nozzle. For more efficient heating of particles in the jet. At the same time inside the plasma torch is necessary to maintain the laminar mode.

For a numerical study of the effect of external acoustic waves on the characteristics of a plasma jet, we use the following approach.

At the first stage, we formulate a model describing the gas-dynamic characteristics of the plasma torch jet. The model is based on the Navier-Stokes system of equations, (the continuity equation, the equations of motion, and the heat transfer equation in a plasma jet). And supplemented by Maxwell's system of equations for electric and magnetic fields, Ohm’s differential law, and heat balance equations for a metal cathode and anode. A more detailed description of the model and boundary conditions can be found in [6].

At the second stage, it is necessary to take into account the effect of external acoustic waves on the plasma jet. On the outer boundary of the plasma torch nozzle, an additional boundary condition on the velocity is specified. The speed varies with time according to the harmonic law

\[
V_{L} = V\left(1 + a_1 \sin(\omega t)\right),
\]  
(4)

where the dimensionless velocity amplitude \(a_1\) varies from 0.01 to 0.1, \(\omega = 2\pi f\). This can be realized by acting on the plasma jet at the outlet of the plasma torch additional gas stream, or by placing at the outlet nozzle of the plasma torch to generate a periodic self-excitation of the jet, leading to oscillation of the jet.

3. Results

Numerical experiments were carried out for different plasma-forming gas flow rates (0.5–4 g/s) and for different discharge currents (100–500 A) for the plasma torch “F4” from Sulzer Metco. As a result of the simulation, the distributions of the main parameters (velocity, temperature, electric and magnetic field potentials) were obtained [4, 6]. Next, external acoustic waves were superimposed using an additional boundary condition for the velocity (4) at the plasma torch output. The dimensionless amplitude of velocity \(a_1\) varied from 0.01 to 0.1, and the frequency from 5 to 50 kHz. Figure 1 shows the results for \(a_1 = 0.5\) and \(f = 20\) kHz.
As can be seen from the above results, the imposition of external acoustic waves leads to periodic broadening of the jet, pulsations of the temperature field, and thus to turbulization of the jet. The results obtained allow us to conclude that the imposition of external acoustic waves will improve the heat transfer between the jet and the particles. This will improve the quality of the coating.

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