Special Aspects of DC Air Plasma Torch's Operating Modes under Turbulent Flow Conditions

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The article is dedicated to the analysis of plasma flow turbulization processes inside DC air plasma torches. The influence of plasma torch's arc current and plasma gas flow rate on plasma flow turbulization inside the torch channel is described. Also, measurements of voltage fluctuation due to motion of point of arc attachment are presented in the article. The mathematical model for the analysis of arc processes inside and outside of plasma torches is developed.

Keywords: plasma torch, spraying technology, turbulence

1 INTRODUCTION

Plasma spray technology is attractive for the materials industry because the temperature generated by an electric arc is much higher than that obtained by gaseous flames.

Plasma spray technology is used for spraying anti-friction (friction reducing), anti-corrosion, heat-resistant and wear-resistant coatings. [1]. The plasma torch creates a thermal plasma flow which is employed for spraying sheet materials and structures of complex shape. Plasma spraying is used for restoration of worn parts, increasing their size to several millimeters [2, 3].

In plasma spray technology process efficiency and quality of the applied coating depend on stability of the plasma flow. Some particles of powder fall into the plasma jet at the time of formation of a new attachment of an electric arc when the temperature field does not meet the criteria of normal heating.

At the moment plasma torches using argon as the plasma gas are widely used in industry. The main problems of these plasma torches:

- instability of the plasma flow;
- low enthalpy;
- plasma jet is short.

The above disadvantages considerably reduce the possibility of using plasma torches, since a large number of materials require a more intensive and longer heating of the powder particles. One of the projects of our department at the SPbSPU is the plasma torch, which extends the reach of spraying technology [4]. Air is used as a plasma gas of this plasma torch which allows solving the problems such as the low enthalpy. Also, the plasma jet becomes longer at the output plasma torch, which increases residence time of the powder particles in the plasma jet and provides the required heating.

One of the most difficult controllable system parameters is the dynamics of the plasma flow. A special geometry of the plasma torch (Fig.1) was developed at our department and it enables more stable plasma flow.

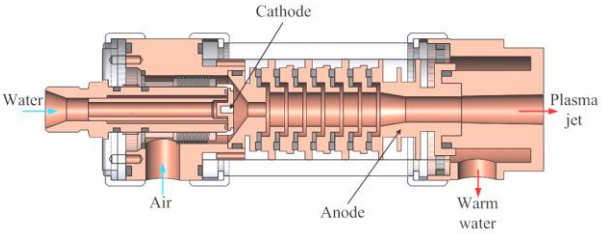

Fig.1: The construction of a DC plasma torch with inter-electrode sections

2 EXPERIMENTAL AND THEORETICAL INVESTIGATIONS

Experimental studies have been conducted to study the modes of operation of the plasma torch. A mathematical model describing the processes occurring inside the plasma torch and the outer border area has been derived.

2.1 MATHEMATICAL MODEL

A two-dimensional mathematical model has been studied using the following assumptions:

- plasma is optically thin;
- the plasma is at Local Thermodynamic

Equilibrium (LTE);
- plasma is treated as a single-phase flow;
- gravity is neglected;
- stationary mode is considered.

In the simplest case, the model can be described by the following equations:

- Energy conservation equation:

$$\nabla\cdot\left(\rho\vec{\upsilon}H\right)=\sigma E^{2}-u_{rad}+\nabla\cdot\left(\frac{\lambda}{c_{p}}\nabla H\right) \tag{1}$$

- Maxwell electro-magnetic equations:

$$\begin{cases}\nabla\times\vec{H}=\vec{J}\\ \nabla\times\vec{E}=-\dfrac{\partial\vec{B}}{\partial t}\\ \nabla\cdot\vec{D}=q\\ \nabla\cdot\vec{B}=0\end{cases} \tag{2}$$

- Momentum equation:

$$\nabla\cdot\left(\rho\vec{\upsilon}\vec{\upsilon}\right)=-\nabla p+\left[\vec{J}\times\vec{B}\right]+\nabla\cdot\left(\mu\nabla\vec{\upsilon}\right) \tag{3}$$

- Mass conservation:

$$\nabla\cdot\left(\rho\vec{\upsilon}\right)=0 \tag{4}$$

The torch geometry corresponding to the real experimental set-up, is presented on Fig. 1. The grid mesh, shown on Fig. 2. The grid mesh consists of 5098 elements.

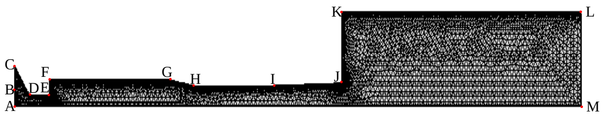

Fig.2: The grid mesh (5098 elements)

Boundary conditions are presented in Table 1. Two models have been implemented in the software Comsol Multiphysics:

- laminar plasma flow model;
- turbulent plasma flow model (*SST-model*)[*].

Table 1: Boundary conditions (see Fig.2)

A-B **(cathode)**	**B-C** **(inlet)**	**C-G** **(wall)**	**G-H** **(anode)**
T_{cath}	T_{wall}	T_{wall}	T_{anode}
$\upsilon=0$	$\upsilon=\upsilon_{in}$ (inlet)	$\upsilon=0$	$\upsilon=0$
$-\sigma\phi_{,n}=J_{cath}$	$\phi_{,n}=0$	$\phi_{,n}=0$	$\phi=0$
$A_{,n}=0$	$A=0$	$A_{,n}=0$	$A_{,n}=0$

H-J **(wall)**	**J-M** **(outlet)**	**M-A**
T_{wall}	$T_{,n}=0$	*Axial symmetry*
$\upsilon=0$	$p_{,n}=0$	
$\phi_{,n}=0$	$\phi_{,n}=0$	
$A_{,n}=0$	$A_{,n}=0$	

2.2 EXPERIMENTAL INVESTIGATIONS

Series of experimental investigations of the temperature and the pressure field fluctuations were produced. The results are shown in Fig. 3 and Fig. 4. Temperature fluctuation is measured by an optical sensor (the total value of emission is measured) and pressure fluctuation is measured by a condenser microphone.

The oscillograph patterns show that the plasma flow is not stable at a low flow rate of plasma gas; the flow stabilizes with the rate increase. The results are confirmed by studies [6].

The oscillation frequency of the pressure increases with flow rate increasing. It is indicating the plasma flow turbulization.

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[*] Model is described in detail at [5].

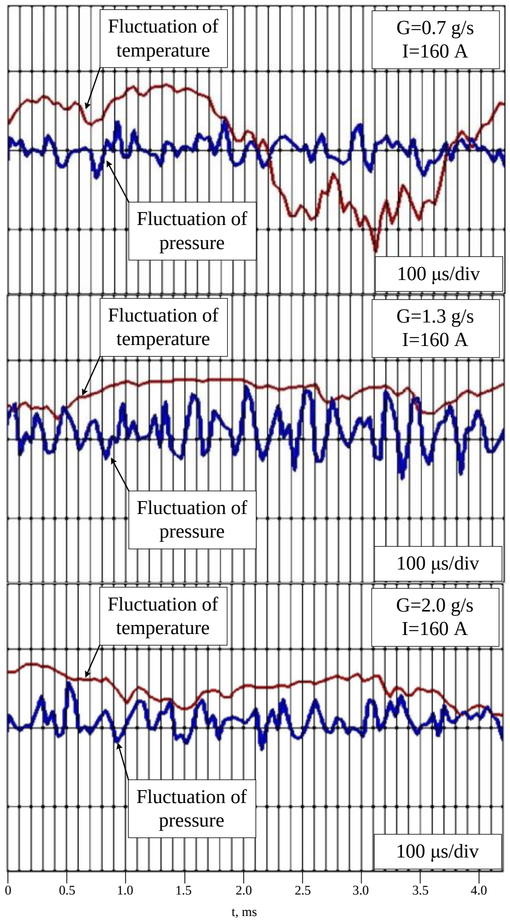

Fig.3: Oscillograms of temperature and pressure oscillations at the current 160A and different gas flow rates

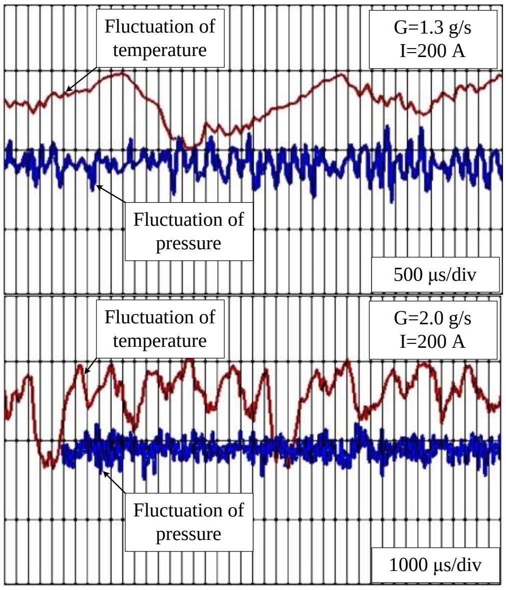

Fig.4: Oscillograms of temperature and pressure oscillations at the current 200A and different gas flow rates

Oscillograms of the voltage (see Fig. 5.) have a sawtooth shape, which indicates the formation of a new point of arc attachment [7], this is also reflected in the erosion of the plasma torch's anode.

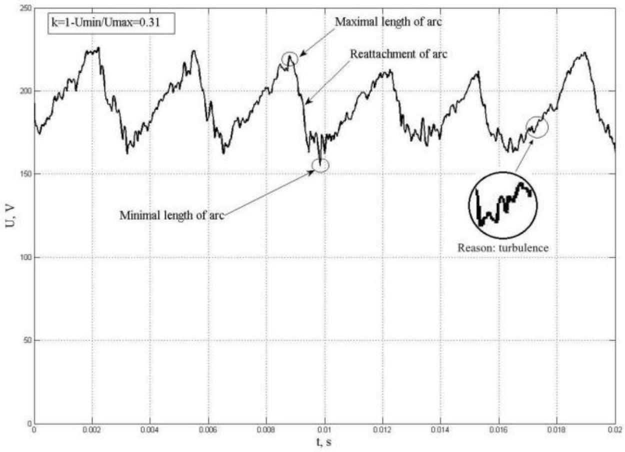

Fig.5: Oscillogram arc voltage

The oscillation frequency is 307 Hz. Absolute ripple factor is 0.31.

3 RESULTS AND DISCUSSION

Magneto-hydrodynamic simulations of the plasma torch were created for two flow types:

- laminar flow;
- turbulent flow (SST-model).

The distribution of the gas temperature for arc current 200 A and laminar flow is shown in Fig. 6.

Maximal gas temperature is 30 000 K.

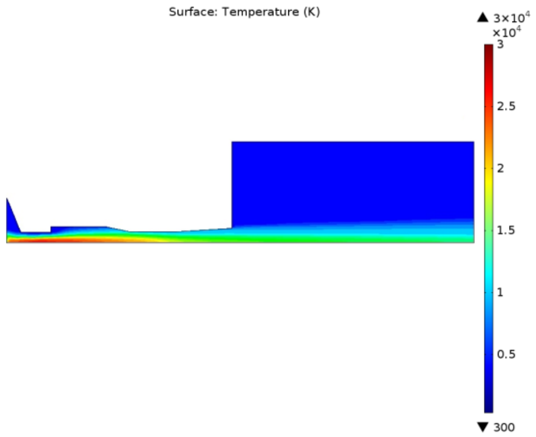

Fig.6: Temperature distribution in plasma torch (I=200 A)

The distribution of the gas temperature for arc current 200 A and turbulent flow is shown in Fig. 7.

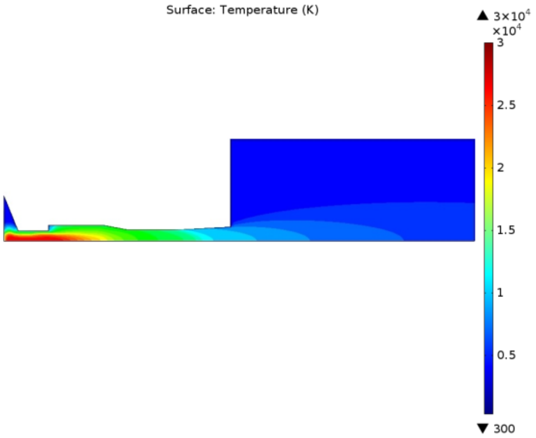

Fig.7: Temperature distribution in plasma torch (I=200 A)

The shape of the temperature distribution (model of turbulent flow) is confirmed by frame from high-speed shooting - see Fig.8.

Fig.8: Image of plasma jet

The distribution of the gas axial velocity (V_Z) for arc current 200 A and laminar flow is shown in Fig. 9.

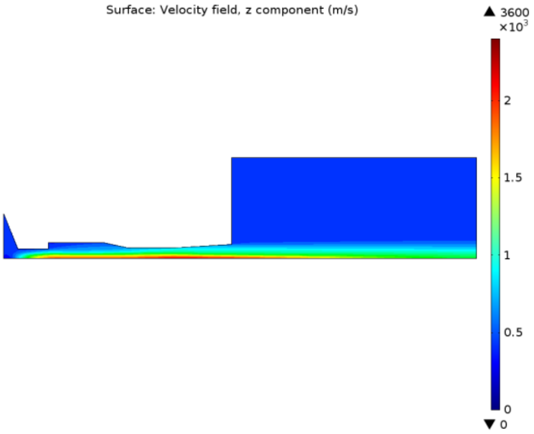

Fig.9: Axial velocity distribution (laminar flow)

Maximal axial velocity of laminar flow model is 3586 m/s.

The distribution of the gas axial velocity (V_Z) for arc current 200 A and turbulent flow is shown in Fig. 10.

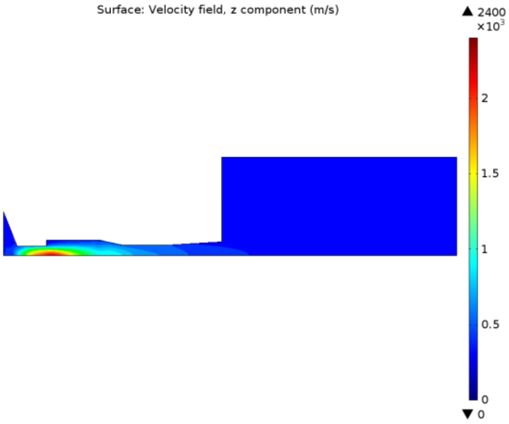

Fig.10: Axial velocity distribution (turbulent flow)

Maximal axial velocity of turbulent flow model is 2378 m/s.

4 CONCLUSION

Modes of operation of the plasma torch at terms of plasma flow turbulization were installed in the plasma torch with the inter-electrode sections.

Turbulent flow model is implemented in Comsol Multiphysics and it corresponds to the results of experimental investigations.

The region of arc attachment is mounted on the anode's diffuser of the plasma torch.

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