Control of the Movement of the Arc in a Segmented Anode Torch

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The reproducibility of the properties of plasma-sprayed coatings depends to a large extent on the stability of the electric arc inside the plasma torch. The stability of the plasma jet in which the coating powder is processed, is affected by the displacement of the anode arc attachment over timescales of the order of a few µs and nozzle erosion over timescale of the order of an hour [1,2]. This erosion depends on the heat load brought by the arc at the attachment point and residence time of the arc root at the same location. Therefore, a major challenge is to achieve as far as possible a stable plasma jet with minimal anode erosion. Segmented anodes consisting of a stack of copper rings insulated from each other and ending with an anode-ring where the arc attaches, are now used in commercial plasma spray torches They make it possible to get more stable plasma jets but the restriction of arc displacement can result in significant erosion. The most common ways to control the distribution of the heat flux to anode are a swirling injection of the plasma-forming gas and application of an external magnetic field [3]. Both are intended to move the arc in a controlled manner in the nozzle.

This study deals with the modeling of the operation of a SinplexProTM torch from Oerlikon Metco *It aims to predict the evolution of the anode temperature when applying an external magnetic field and compare it with the only actual gas vortex injection.*

The electrode geometry of the SinplexProTM torch is shown in Fig. 1.

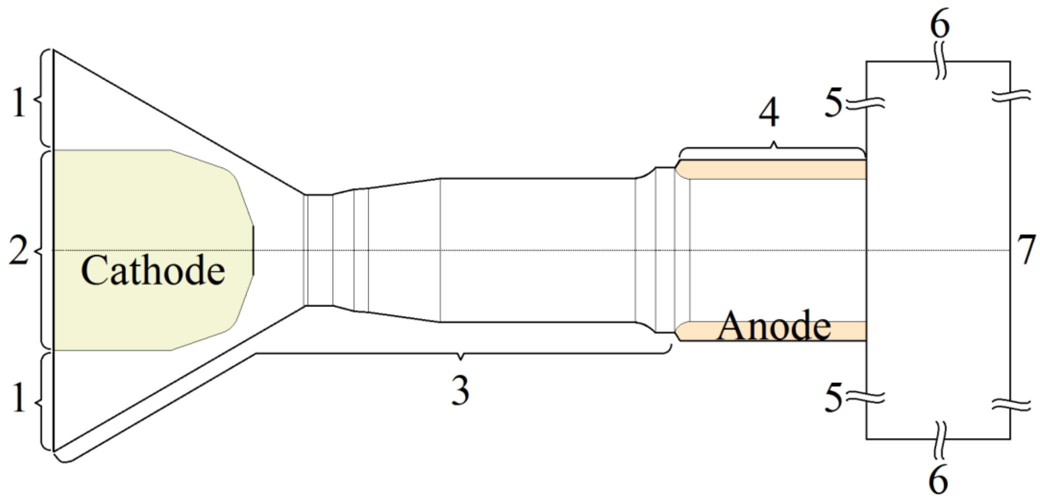

Figure 1: Geometry of electrodes and boundaries of the computational domain: 1: inlet of plasma-forming gas; 2: rear of the cathode where the current density (I/S) is imposed; 3: electrically insulating inter-electrode; 4: anode; 5 and 6: cold wall; 7: outlet

A MHD, 3-D and transient model of the plasma torch operation was developed to predict the effect of the external magnetic field on the stability of the plasma and heat load to the anode. The model was implemented in the open-source CFD software Code_Saturne. The model coupled the plasma phase and electrodes in order to follow the evolution of the temperature of the electrodes. The coupling used a special boundary condition i.e. thin virtual walls between the gas phase and electrodes. This numerical trick is imposed by the discontinuity of enthalpy at the metal-gas transition. The boundary conditions imposed on these walls were the continuity of temperature, thermal flux, electric current and electric potential. Additional heat sources in the electrode interface cells originated in the heat transfer from the gas phase to electrodes by the electrons coming to the anode and ions coming to the cathode. Also, the electrons emitted by the cathode hot surface cooled its interface cells. The boundary conditions used in the model are presented in Table 1. The mesh consisted of 1.7 10^6 grid cells.

Table 1: Boundary conditions. The number in the first column corresponds to the boundaries of the domain shown in Fig. 1.

Variable:	$\vec{u}$	T	φ
1: Inlet	$\vec{u} = \vec{u}_{inlet}$	T=300K	$\partial_n \varphi = 0$
2: Cathode	$\vec{u} = 0$	T=300K	$\varphi = \Phi_{recomputed}(t)$
3: Fluid boundary	$\vec{u} = 0$	T=300K	$\partial_n \varphi = 0$
4: Anode	$\vec{u} = 0$	T=400K	$\varphi=0$
5: Outside plain wall	$\vec{u} = 0$	T=300K	$\partial_n \varphi = 0$
6: Outside cylindrical wall	$\vec{u} = 0$	T=300K	$\partial_n \varphi = 0$
7: Outlet	$\partial_n u_i = 0$	$\partial_n T = 0$	$\partial_n \varphi = 0$

The numerical simulations were performed with Argon as plasma forming-gas with a flow rate of 60 NLPM and electric arc current of 500 A. The nozzle diameter was 9 mm and the plasma torch was operated at atmospheric pressure. The experimental arc voltage is 76±4 V while the predicted one is 74 V.

It should be first noted that the inclusion of the electrodes helps not only to predict their surface temperature but also to improve the predictions of the self-induced magnetic field. If the electric current distribution inside the electrodes is disregarded, the self-induced magnetic field ids underestimated by around 50% in the electrodes vicinity due to the omission of a half of the conducting channel.
The field of the magnetic field self-induced by the electric arc is shown in Fig. 2.

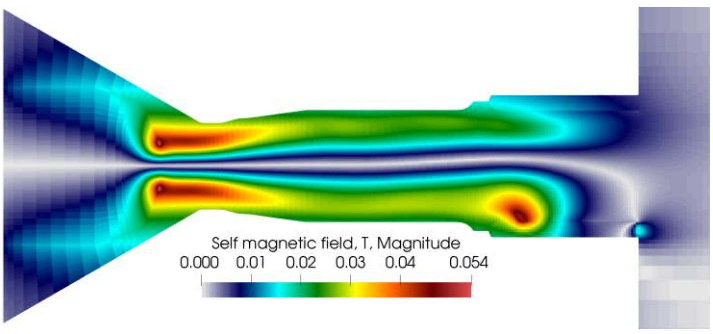

Figure 2: Magnetic field self-induced by the electric arc between the cathode tip (left) and cylindrical nozzle (right).

Figures 3 and 4 show the predicted time-average axial and circumferential velocity distributions of the arc when only the gas swirling injection is used. The axial velocity component is two orders of magnitude higher than the circumferential one. The strength of the swirl can be gauged by the swirl number Sw (Eq. 1) defined as the ratio of the axial flux of the tangential momentum to the axial flux of the axial momentum. Under the conditions of the study, Sw is around 0.25 in the middle of the channel and around 0.1 at the nozzle exit. The predicted swirl numbers are very low and so will not be very efficient to control the anode temperature evolution [4].

$$S_W = \frac{\int_0^R \rho w u r^2 dr}{R_0 \int_0^R \rho u^2 r^2 dr} \quad \text{(Eq.1)}$$

where ρ is the gas density, w is the circumferential velocity component, v is the axial velocity component, r is the radius of the cross section in which the swirl number is computed and R_0 is the torch nozzle radius.

To have a more significant effect of the swirling injection, additional concurrent or counter-current swirling gas flows between the inter-electrode inserts and much steeper inlet angle up to 90° could be used as proposed by Zhukov [5].

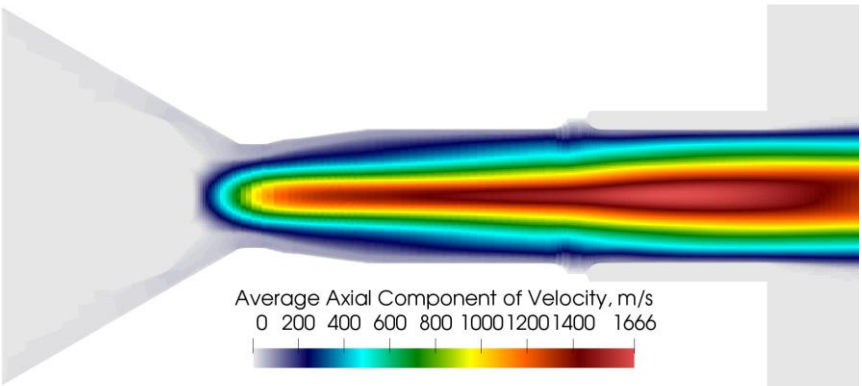

Figure 3. Time-averaged arc axial velocity component

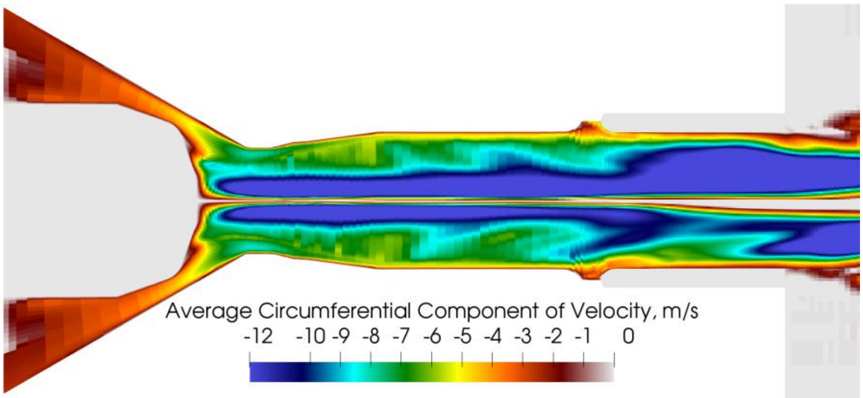

Figure 4. Time-averaged arc circumferential velocity component

During the operation of the SinplexPro plasma torch it was observed that when an erosion spot appears on the anode surface, the arc attachment keeps a fixed angular position corresponding to the erosion spot. The predicted time of the anode melting process with an arc current of 500 A is around 10 ms. The present model cannot simulate the deformation of the anode surface due to heat load erosion and so no specific location is more attractive for the arc that can move on the whole anode surface without any obstacle. This explains why no specific arc attachment can be predicted by the model: the arc is slowly and continuously moving under the weak effect of the gas swirling injection. Therefore, the effect of the swirling injection and external axial magnetic field can only be compared in terms of the circumferential velocity of the anode arc attachment.

The projections show that even a weak external magnetic field of 0.05 T has a significantly higher impact on the arc motion than the swirling inlet experimentally used in the plasma torch. The chosen axial external magnetic field has the same order of magnitude as the self-induced azimuthal one. The arc circumferential velocity of the anode arc attachment with only the swirling argon flow was 8 m/s, while with the axial external magnetic field the arc velocity reached 27 m/s.

In addition, the anode started melting only if the arc had the same angular position for a time period of about 10 ms. However, as soon as the arc started rotating, with a speed at least of 10 m/s, the maximum anode temperature decreased below 1000 K. At the same time with the used values of the external magnetic field the plasma jet issuing from the torch retained its stability and straightness (Fig.6).

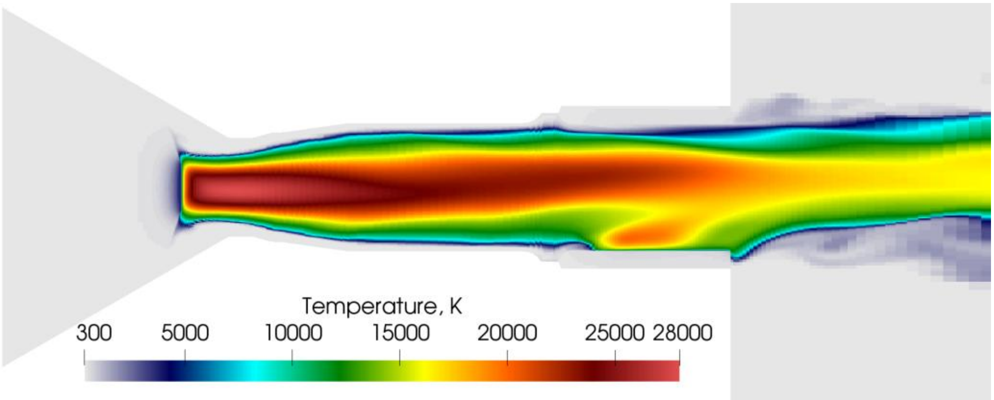

Fig. 6. Temperature distribution with an external magnetic field of 0.05 T

Acknowledgments

The authors would like to thank Alexander Barth and Hartmut Koschnitzke, Oerlikon Metco Wohlen, Switzerland, for valuable discussion and Frederic Bernaudeau and Nicolas Calvé, IRCER, for their technical help with the computers.

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