Three dimensional nonequilibrium numerical simulation of anode region of high intensity transferred arc

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Abstract: A three-dimensional chemical non-equilibrium plasma model is developed and applied to the simulation of a high intensity argon transferred arc with cross flow. The modelling result shows the arc attachment position is determined by the balance between the gasdynamic drag force and the Lorentz force. Compared to the symmetric distribution of case without the cross flow, an asymmetric distribution of Lorentz force with larger value upstream is formed to act on the plasma flow against the cross flow.

Keywords: high intensity argon arc, cross flow, chemical non-equilibrium model.

1. Introduction

Direct-Current (DC) electric arcs device have been widely used in various industrial applications in the past several decades. Depending on the design of the torch, powers up to several MW can be produced, although 100–200 kW is more typical [1]. In these applications, erosion of the anode surface caused by the anode-arc attachment may substantially reduce the lifetime of the anode due to the fact that anode is frequently subject to extremely high heat transfer rates. Therefore, the investigation of arc attachment at the anode continue to attract considerable attention.

In a typical non-transferred dc plasma torch, the anode surface is parallel to the gas flow and the arc axis, forcing the arc anode attachment to be perpendicular to it. Consequently, the anode attachment is exposed to a strong dynamic drag force resulting from the interaction between the gas flow and the arc anode attachment. The strong interaction of electromagnetic, thermal, and gasdynamic effects especially in the anode region leads to the reasonable and accurate description of arc behaviour with cross flow processes in thermal plasma systems, which is quite difficult. Although a considerable effort by many of these investigators has been expended in an attempt to achieve a good understanding of these phenomena, our knowledge of arc behaviour in the anode region still remains incomplete.

The behaviour of the arc-anode attachment in the non-transferred plasma torch is difficult to investigate by either experiments or numerical simulations. The plasma torch has such a small diameter that any diagnostic devices cannot be placed inside the torch. Therefore, quite limited information concerning the arc behaviour inside plasma torch can be used for the analysis and comparison with numerical simulation. The arc attachment in a transferred plasma with a cross flow, developed by Pfender and Heberlein's Group [2], is a good substitute for the non-transferred plasma torch. This kind of high intensity wall-constricted arc system allows direct observation of interaction between DC arc and cross flow. All these efforts have been successful in increasing our understanding on arc behaviour near anode region.

The purpose of this study is to investigate the behaviour of the high intensity transferred arc attachment on the anode interacting with the cold cross flow by numerical simulation. General three-dimensional conservation equations and some auxiliary relations for the simulation of arc flows will be established and applied for the simulation of the arc-root attachment at the anode surface. The position of this attachment will be analysed by the comparison between the gasdynamic drag force and the Lorentz force.

2. Numerical Approach

The proposed model is based on a wall-stabilized arc device with the cross cold flow. The structure, geometry and operating parameters of this device used in this simulation are almost the same as those of experiment setup used in experimental investigation of Yang [3]. The anode region of such an arc is shown schematically in Fig. 1 with the plane anode normal to the axis of the arc. Argon is used as the plasma working gas and the injected lateral gas.

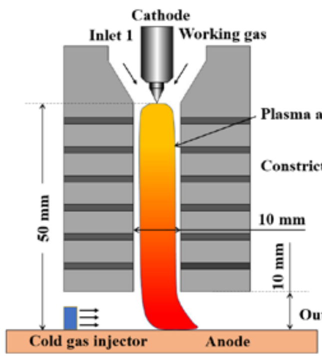

Fig. 1. Schematic diagram of the transferred arc plasma torch with cross cold gas injection

The main assumption used in this study includes that the arc is steady, rotationally symmetric, and is operated with a plane anode perpendicular to the arc axis. The flow is laminar and incompressible—an assumption justified by the very low Mach numbers. Only the self-induced magnetic field of the arc is considered (no external magnetic fields). Gravity and heat dissipation due to viscosity effects are negligible. A multi-component (atoms, excited atoms, ions, molecular ions and electrons), two-temperature argon arc plasma is considered in which atoms and ions have the same translational temperature which is different from that of the electrons. The plasma is assumed to be in chemical (ionization) nonequilibrium and its composition is calculated assuming ionization reactions and diffusion [4].

A set of 3-D governing equations, including mass-averaged momentum equations, electron and heavy-particle energy conservation equations, species mass conservation equation, potential equation, and magnetic vector potential equations, are solved simultaneously with appropriate boundary conditions.

3. Modelling Results

In this simulation, the computation domain includes the plasma arc in anode region and of an arc constricted by a 10-mm-diameter tube up to an axial location 50 mm from the anode. In order to focus the arc behaviour in anode region, only the parameter distributions between the exit of constricted tube and anode are presented in the following section.

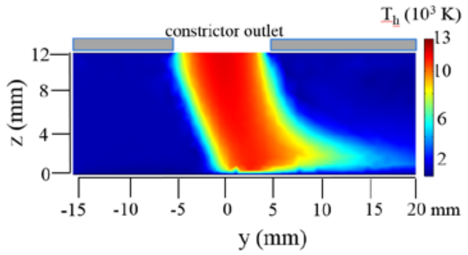

Fig. 1. Distribution of heavy-species temperature in the y-z plane at an arc current of 100 A

It can be seen from the Figure 1 that the left side of the heavy-species temperature, which faces the cross flow, is cooled down significantly resulting in steep temperature gradients, compared to the low slope of the opposite side. The high temperature plasma region becomes narrow and extends toward the anode, leading to elongated high-temperature strip. The maximum temperature deviates from the y = 0 axis due to the cross gas flow.

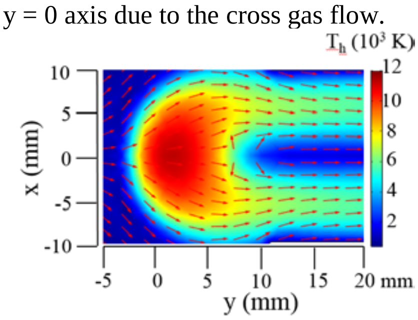

Fig. 2. Cross section view of heavy-species temperature distribution with arc current of 100 A

As shown in Fig.2, since the plasma flow is more viscous than the cold cross flow, the plasma column acts like a solid obstacle to the cross flow. Then, drag of the cross flow affects predominantly the low-viscosity layer of the plasma flow, leading to a horseshoe temperature distribution.

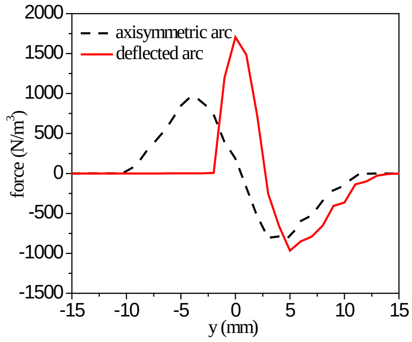

Fig. 3. Distribution of Lorentz forces for the deflected arc (a) and stable diffuse arc (b) above the anode surface.

Lorentz forces distribution can be obtained by three-dimensional numerical simulation as shown in Fig. 3. The result shows that the distribution of Lorentz force is not symmetric with cross flow compared to the symmetric distribution of Lorentz force without cross flow. The value of Lorentz force with cross flow is larger than that without cross flow, especially for the left side of Lorentz force, which is caused by the higher current density for the side with cross flow. These results indicate that 3D modelling is required to capture the physical pictures of the arc in cross gas flow.

4. Conclusion

Three-dimensional chemical non-equilibrium modelling is performed to investigate the effect of cross gas flow on the plasma characteristics in a high intensity transferred arc. The results show that with the cross gas flow, the plasma column acts like a solid obstacle to the cross flow. Drag of the cross flow affects predominantly the low-viscosity layer of the plasma flow, leading to a horseshoe temperature distribution. The arc attachment position is determined by the balance of different forces acting on the plasma.

5. Acknowledge

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