Experimental study on the dynamic behaviour of nitrogen arc root on the anode in the presence of laterally-blown gas

Ya-hao Hu[1, 2], Su-rong Sun[1], Xian Meng[2], He-ji Huang[2], Jin-wen Cao[2], and Hai-xing Wang[1, 3]

[1] *School of Astronautics, Beihang University, Beijing, China*
[2] *Institute of Mechanics, Chinese Academy of Sciences, Beijing, China*
[3] *Ningbo Institute of Technology, Beihang University, Ningbo, China*

Abstract: In this study, the dynamic behaviour of nitrogen arc root on the anode with argon as laterally-blown gas are studied by using the high-speed camera. The results show that in one restrike cycle, the instantaneous velocity of the anode arc root increases and then decreases. During the acceleration phase of the arc root motion, the flow rate of the lateral gas hardly affects the acceleration of the anode arc root, but the change of the arc current has a significant effect on the acceleration of the arc root motion in the initial phase of restrike.

Keywords: Thermal plasma, arc anode attachment, restrike mode, movement characteristics

1. Introduction

As a high temperature heat source with high energy density and large parameter gradient, DC arc plasma devices are widely used in aerospace, material processing, environmental protection and other fields [1]. In the typical non-transferred arc plasma commonly used in industry, the rod-shaped cathode is arranged in parallel with the anode, which causes the gas flow direction to be perpendicular to the arc attached to the anode surface. The arc anode attachment is exposed to strong gas-dynamic drag force exerted by the gas flow, causing the instability of the arc attachment and presenting different attachment modes, such as takeover and restrike mode. The instability of the arc attachment leads to large magnitude of arc voltage fluctuation, which directly affects the power input, arc and jet characteristics, which has a great influence on the performance of the device. To observe the arc anode attachment behaviour under the action of lateral gas flows, Yang [2] developed a wall-stabilized transferred arc device. They focus on the transition from a steady mode to a takeover mode and finally to a restrike mode. It was found that electron overheating instability plays an important role during the transition, and it is driving mechanism for the transition of anode attachment in arcs without cross flow. Despite a large number of previous simulation and experimental studies on the arc flow dynamics [2], heat transfer [3], chemical kinetics [4] and jet characteristics [5] within the plasma torch have been carried out, the understanding of the motion characteristics of the anode arc root in restrike mode is still insufficient due to the extremely difficulty in experimental observation. In this study, a transferred arc device is used to observe the arc root restrike behaviour on the anode. The results are helpful to improve our understanding of the physical mechanism of the anode arc root movement.

2. Experimental setup

The general layout of the experimental system used in this study is shown in Fig. 1. The transferred arc device is placed in an experimental chamber with a diameter of 600 mm and a height of 550 mm. The thoriated tungsten cathode is a 5 mm diameter cylinder with a 60° cone angle at its tip portion. The planar copper anode with a diameter of 60 mm is placed parallel to the cathode with a separation of 5 mm, chosen to simulate the relative position of the two electrodes inside the DC arc plasma torch. Both cathode and anode are cooled by cooling water. An IGBT inverter DC constant-current power supply is used, and the current is adjustable in the range of 40-160 A. In the experiments reported here, the arc-forming gas was nitrogen, and argon was used as the shielding gas. The arc-forming gas was supplied through the channel between the cathode and the alumina ceramic nozzle. The laterally-blown gas is provided by a gas distributor, which is placed directly above the anode and below the cathode, as shown in Fig. 1. The gas distributor has 5 evenly distributed small holes of 1 mm diameter so that the gas flow direction is parallel to the anode surface. A monochromatic high-speed camera (i-SPEED 513) with a neutral density filter is used to directly observe the arc behaviour. The frame rate is set to 50,000 fps, which is high enough to capture the dynamic behaviour of the arc during the restrike process. The arc voltage is obtained by measuring the voltage difference between the electrodes using a voltage probe (Tektronix TPP0500B) and a digital oscilloscope (Tektronix MDO3034).

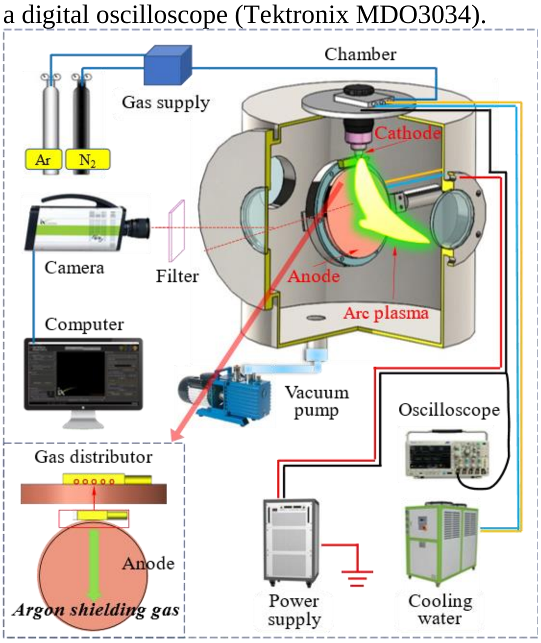

Fig. 1. Schematic of the experimental setup.

3. Results and discussions

A comparative experiment based on the planar anode was conducted to investigate the effect of argon lateral gas flow rate and arc current on the anode arc root movement characteristics. Fig. 2 exhibits the instantaneous velocity and the arc length of the anode arc root in one restrike cycle under different conditions. The position of the anode arc root is obtained by processing the pictures recorded by the high-speed camera frame by frame in a self-designed Matlab program. The instantaneous velocity of the anode arc root is determined by the central difference of the arc length versus time.

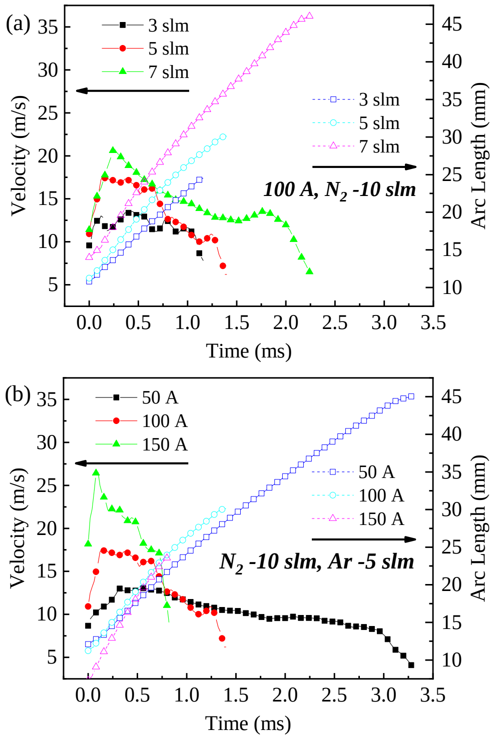

Fig. 2. The anode arc root movement characteristics, (a) with different lateral argon gas flow rates, (b) with different arc currents.

As shown in Fig. 2(a), the instantaneous velocity of the anode arc root first increases and then decreases in a restrike cycle. Both the maximum instantaneous velocity and the maximum arc length increase with the increase of lateral argon gas flow rate at a constant current due to the aerodynamic force and low ionization rate of the lateral gas. Fig. 2(b) exhibits the instantaneous velocity and the arc length of the anode arc root under different arc current. It can be seen that, the maximum instantaneous velocity increases with the increase of arc current, while the maximum arc length decreases with the increase of arc current. By comparing Fig. 2(a) and Fig. 2(b), we can find that the maximum velocity increases with the increase of the lateral argon gas flow rate and arc current, while the flow rate of the lateral gas hardly affects the acceleration of the anode arc root, but the change of the arc current has a significant effect on the acceleration of the arc root motion in the initial phase during the acceleration phase of the arc root motion.

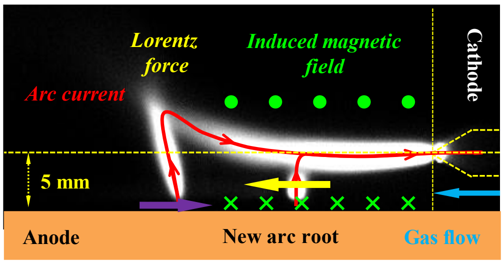

Fig. 3. Schematic of the force on the arc.

Fig. 3 exhibits the schematic of the force on the arc at the restrike moment, when the new anode arc root just formed in the upstream and the old arc root downstream has not disappeared. At this time, there are three forces acting on the new arc root, which are the Lorentz force pointing downstream generated by the interaction between the arc root and arc column's self-induced magnetic field, the aerodynamic drag force pointing downstream generated by the interaction with the lateral gas flow, and the viscous force interacting with the anode wall. It can be seen from Fig. 2, the slope of instantaneous velocity hardly changes with the increase of lateral gas flow at the constant current, but the slope of instantaneous velocity increases with the increase of current significantly for the case of constant lateral gas flow, which illustrates that the Lorentz force dominates in the initial phase of restrike.

4. Conclusion

In this paper, the experimental study has been carried out for a transferred arc device to investigate the nitrogen arc root movement along the anode in the presence of laterally-blown gas. The results show that the arc length increases with the increase of lateral argon gas flow rate at a constant arc current, while the arc length decreases with the increase of arc current. It is found that the instantaneous velocity of the anode arc root increases and then decreases in one arc restrike cycle. and the maximum velocity increases with the increase of the lateral argon gas flow rate and arc current, but the effect of the arc current is more significant than that of lateral argon gas during the acceleration phase of the arc root motion.

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