Gasdynamic dispersing of nitrogen arc in thermal plasma generator

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Abstract: For dispersing the arc column and making a diffused attachment of the arc root on anode surface, a special anode structure was designed which has an arc channel with flow-restrictor of 3 mm diameter and downstream expansion half-angle of 5°. A sufficiently diffused attachment of nitrogen arc root on the anode surface could be obtained when the gas flow rate was high enough and the thermal blocking existed in the restrictor, due to the strong gasdynamic expansion effect at the divergent section of the anode. This caused almost no erosion of the anode at arc current lower than 150 A in accumulated 40 h running time.

Keywords: Nitrogen arc, diffused arc-anode attachment, gas dynamic expanding effect.

1. Introduction

Very limited service life caused by the electrode erosion is still a well know bottleneck of non-transferred arc plasma generator, especially for working under high arc current conditions, though this kind of generators has been extensively studied and widely applied for decades [1]. This is because that the attachment of the arc root is generally constricted in a very small area on the cold electrode surface, by which the density of energy transfer to the local surface of the electrode is extremely high and local erosion of surface melting and evaporation is difficult to be avoided. Moving the attachment point of arc root to scan large area on the electrode surface [2-3] is the common way to avoid the rapid local damage and to get relative long service life of the anode. And reducing the arc current by increasing the arc voltage [4] and/or dividing the arc current by multi-set of electrodes [5] are also general methods to decrease the attachment current density. However, the arc root attachment constricted in a local area on the water-cold anode surface with very high current density cannot be basically altered by these normal ways.

Through suitable combination of the plasma generator design and the operating parameter, possibility of dispersing the arc column before it reaches the anode surface was explored [6-7] in a reduced pressure environment. That is to make the arc column expanding to a larger-volume by relative strong gasdynamic expansion action, thus to form a diffused attachment with much lower current density than the condensed attachment on the anode surface, avoiding deep erosion at local position on the electrode.

In the present work, a direct current non-transferred arc plasma generator with similar structure as the one in the work [6-7] was used, to investigate the effects of gas situation and arc current on the attachment behavior of arc root on the anode surface, and hence the erosion situation of the anode as the change of working condition, in atmospheric environment.

2. Experimental conditions

Different from the previous work, no gas protecting or control chamber and pumping system were used in this work, and the working environment was atmosphere. That is, in this work, the pressure and environment gas at the exit of the anode nozzle were always 1 atm and air. Gases used for producing the plasma were nitrogen and nitrogen/argon, at flow rates between 9-34 slm. The plasma generator has the similar anode structure as in [6-7] with a flow-restrictor of 3 mm diameter and a downstream expansion half-angle of 5°. The pressure in the cathode chamber was measured with a transducer connected to an oscilloscope. Arc current was set at between 80 A - 147 A. Transducers connected to the oscilloscope were used to measure the arc current and arc voltage. Temperature difference between the outlet and inlet of the generator cooling water was measured with copper-constantan thermocouples, and the thermal efficiency was estimated combined with the flow rate of cooling water.

The main system setup was similar to [6-7] except the atmospheric control chamber. A self-designed copper mirror with a weakly-reflecting central portion was used to observe the attachment behavior of the arc root on the anode surface. The purpose of the weak-reflecting center part of the copper mirror is to reduce the reflection of strong emission light from the arc column of high current-density in the restrictor channel, to enable clear observation of the light signal from the diffused attachment of the arc root in the expansion section of the anode. Fig.1 shows a plasma jet situation and the setup condition between the generator and copper mirror. An ICCD device and a general digital camera were used to record the condition of the arc in the anode channel and plasma jet.

Fig.1 A picture of the plasma jet flow. Copper mirror can be seen at the bottom of the picture.

3. Results and discussions

Measured cathode cavity pressure is shown in Fig.2. The pressure increased apparently with the increasing nitrogen flow rate. It increased from 110 kPa to 160 kPa as the nitrogen gas flow rate increased from 10 slm to 30 slm. But the arc current indicated a wake effect on the pressure change as shown by the hollow markers in Fig.2. The increased pressure of higher than 1 atm in the cathode cavity was caused by the heat blocking effect in the restrictor section of the anode, by which the gas expansion could dispersing the arc column in the divergent section of the anode nozzle.

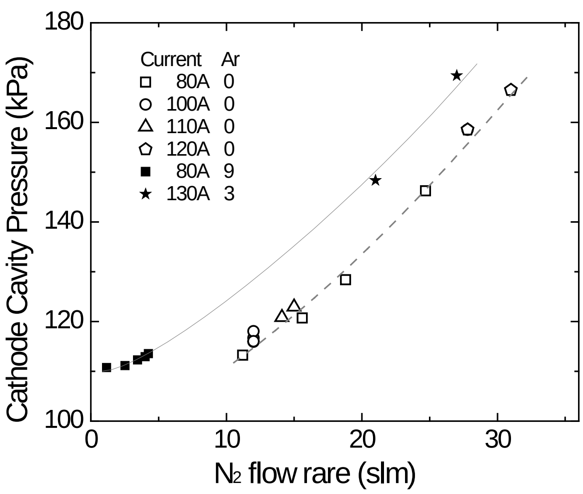

Fig.2 Variation of the cathode cavity pressure as the nitrogen gas flow rate, at arc current 80A-130A.

Figure 3 shows that pure argon (line 1), pure nitrogen (line 2) and mixture of argon/nitrogen (line 3) working gases have all the decreased voltage-ampere characteristics. The arc voltage decreased slowly with the increasing arc current, when the plasma working gas flow rate was fixed at a constant value, no matter what kind of gas was used. The line 4 indicated that the arc voltage increased rapidly with the increasing gas flow rate, though the arc current increased at the same time. These means that the gas flow rate affected the arc voltage much stronger than that arc current did for the present generator.

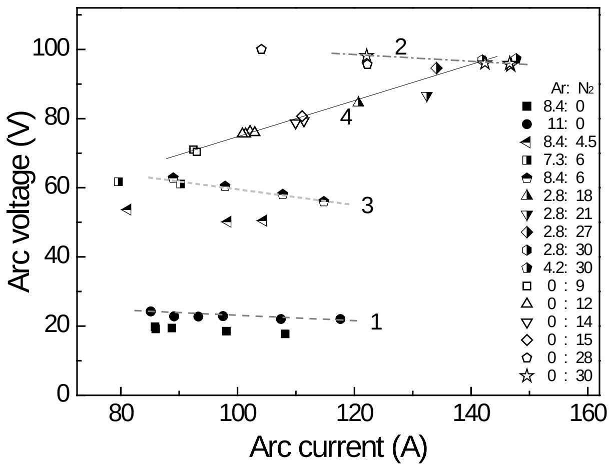

Fig.3 Arc voltage changes with the arc current and gas flow rate.

Arc root attachment situations on the anode surface are shown in Fig.4, taken by the normal digital camera with a filter of 1% light transmittance at 250 μs exposure time. Comparing Fig.4 a) and b) at the same arc current and nitrogen gas flow rate, addition of small amount of argon gas caused the intensity increasing and broadening of the luminous reflecting the arc root attachment. Increasing the arc current from 100 A to 130A and keeping the gas flow rate unchanged, the luminous intensity increased clearly as shown in Fig.4 b) and c). According to the pictures, it is estimated that the arc attached in a spread region to 33 mm of axial direction from the restrictor exit with an area of ~500 mm^2, by which the average current density is ~10^5 A/m^2, about two orders lower than the density over 10^7 A/m^2 of the arc column at the restrictor section.

Pictures in Fig.5 show the arc root attachment conditions with different gas component and flow rate at different arc current, taken by the ICCD camera at 5 μs exposure time. These pictures indicate the same tendency as in Fig.4, though they have much shorter exposure time collecting a instantaneous lighting information of the arc root attachment. These results suggest the sufficient dispersing and diffused attachment of the arc.

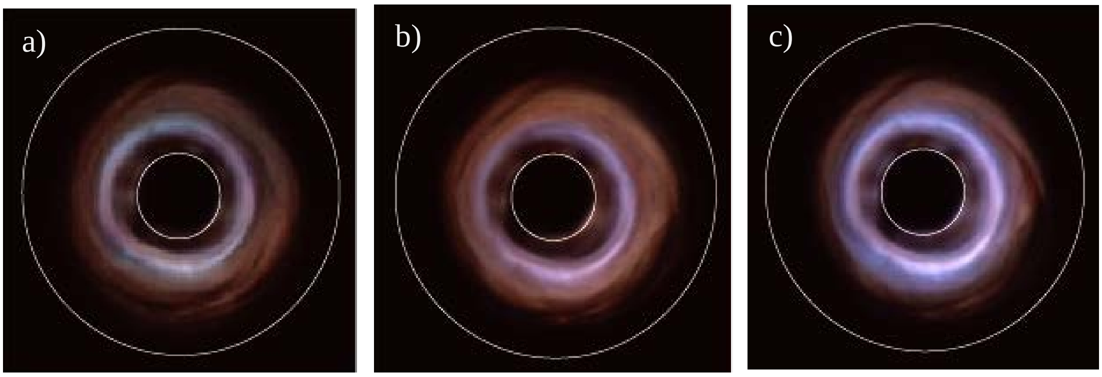

Fig.4 Pictures taken by the normal digital camera with a filter of 1% light transmittance at 250 μs exposure time. a) N_2 gas at 12 slm flow rate and 100 A current; b) N_2 12 slm and Ar 3 slm at 100A; c) N_2 12 slm and Ar 3 slm at 130A.

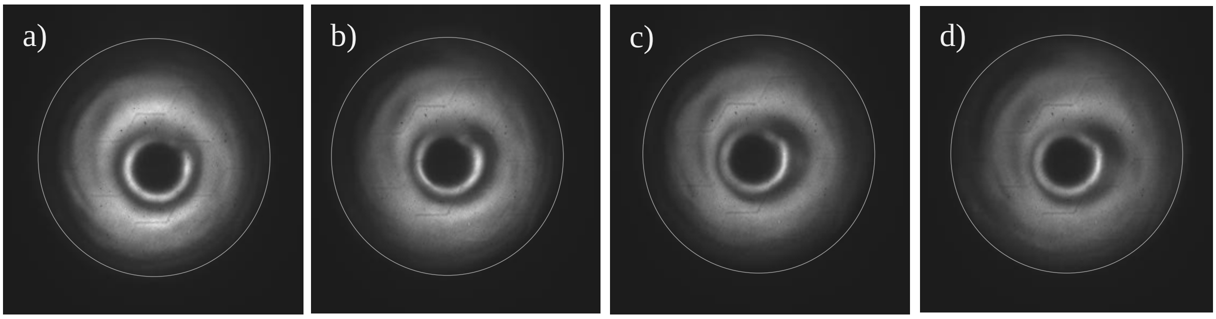

Fig.5 ICCD pictures show the arc root attachment situation with the same exposure time 5μs. a) N_2 gas of 12 slm at current 100 A; b) N_2 14 slm at 110 A; c) N_2 21 slm and Ar 2 slm at 130 A; d) N_2 30 slm and Ar 2 slm at 140 A.

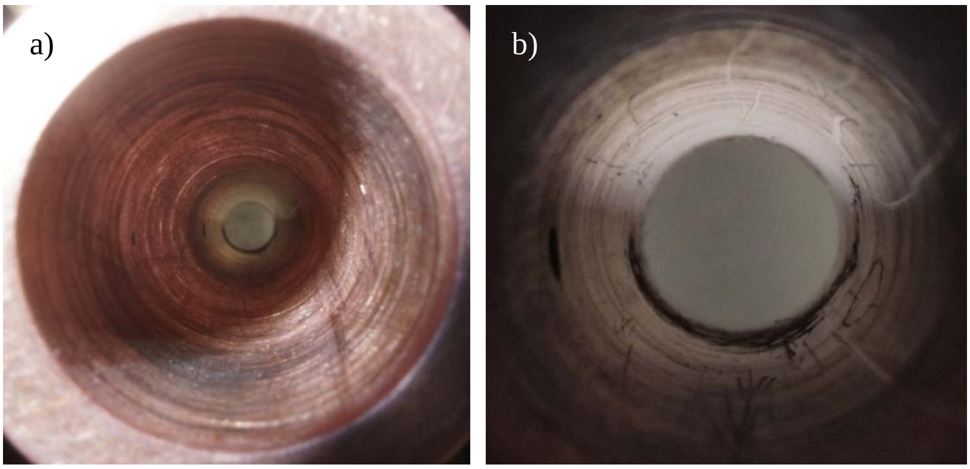

Fig.6 Anode surface condition after 40 h accumulated ignition time at arc current ~147 A

After an accumulating ignition time of 40 h under the various working conditions described in the experimental section above, the machining imprint for producing the anode nozzle can still be seen clearly, and there are almost no erosion traces on the anode surface in the divergent section, on which the arc root attached, as shown in Fig.6. A shallow erosion trace can be seen on the anode surface near the exit of restrictor, as shown in Fig.6 b). This slight erosion at or near the restrictor wall was identified to be formed under the working conditions at very low gas flow rate. No thermal blocking occurred in the restrictor, and arc column could not or just pass through the restrictor section, making attachment on the wall of restrictor or near its exit in a condensed attachment form, because of the low cathode cavity pressure.

Figure 7 shows that the thermal efficiency of the plasma generator increased apparently with the increasing flow rate of the nitrogen working gas. The arc current affected the thermal efficiency relatively weaker than the effect of gas flow rate, and the efficiency decreased with the increasing arc current. The thermal efficiency was over 60% at low current 80 A and high gas flow rate of 25 slm.

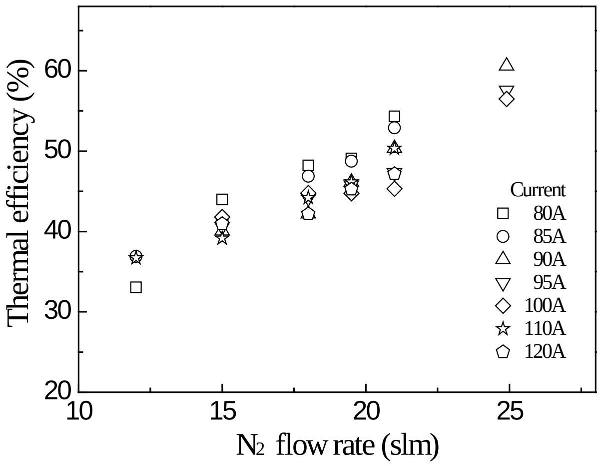

Fig.7 Thermal efficiency changes with the flow rate of nitrogen gas and arc current.

4. Summary

Nitrogen arc column could be dispersed sufficiently, and then attached with diffused state on the anode surface in the divergent section of the plasma generator working at atmospheric environment. Relative high gas flow rate is favorable to cause adequately gas expansion by the gasdynamic action and hence the diffused attachment of arc root, and to lead to ignorable anode erosion and high thermal efficiency of the generator.

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