Arc behavior in a divergent channel with inter-electric inserter and anode

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Abstract: A direct current arc plasma generator was designed for very low erosion rate of its anode working around 100 kW input power with nitrogen or air as the working gas. The main characteristics of the generator design is that an inter-electric inserter with flow restrictor and downstream expansion section was set between the cathode and anode. At arc current 100A-370A, the arc voltage increased up to 330V as the gas feeding rate increased up to 400 slm. Results show a relatively dispersed arc root attachment on the anode surface, and no deep local erosion could be observed in the working parameter range.

Keywords: Air arc, nitrogen arc, insert structure, gasdynamic effect, low anode erosion.

1. Introduction

Normally, current density at the arc-root attachment point on anode surface of a non-transferred direct current (dc) arc generator is exceedingly high. This always cause quick and local deeply erosion of the generator electrode, and has been the main bottleneck limiting the effective utilization for long-duration operation and low erosion contamination. There are many methods to extend the service time of electrodes [1-2], and most of them are spreading out the ablation area but could not reduce the total ablation amount.

Our previous work had designed and operated the generator of special anode structure with small size flow restrictor section and divergent expansion section, to disperse the arc column and to make sufficiently diffused attachment of the arc rote on the anode surface [3-5]. Results showed that nitrogen arc and hydrogen arc column could be dispersed sufficiently, and attached with diffused state on the anode surface. High gas flow rate is favorable to cause adequately gas expansion in the divergent section and hence to bring out the sufficiently diffused attachment of arc root. Ignorable anode erosion occurred, with accumulated ignition time over 40 h at the arc current of lower than 150 A.

In the present work, a dc arc plasma generator with an inter-electric inserter between the cathode and anode was designed for around 100 kW input power and low erosion of its anode. Characteristics of the generator was estimated with nitrogen and air as working gases of the plasma injecting into the atmospheric environment.

2. Experimental conditions

Main difference with the previous generator design [3-5] is that an inter-electric inserter is set between the cathode and anode, as shown in Fig.1. The inserter has the structure of arc channel with flow-restrictor of 5 mm diameter and downstream divergent section of 6° expansion half angle, to disperse the arc column by gasdynamic expansion action and hence to reduce the current density attaching on the anode surface at downstream of the inserter. Pure nitrogen, air and nitrogen/argon mixture were used as the plasma working gas respectively. The hafnium alloy was used as the cathode material to adapt the air discharge condition. Working gases were fed by two passages separately into the cathode cavity (main gas) and between the inserter and anode (auxiliary gas), and the plasma jet was injected into atmospheric environment. The arc current was set at 100 A - 370 A, and the gas feeding rate up to 400 slm in total (sum of the main and auxiliary gas flow rate).

Pressure in the cathode chamber was measured with a transducer connected to an oscilloscope. Temperature difference of the generator cooling water between the outlet and inlet was measured with copper-constantan thermocouples. Thermal efficiency of the plasma generator was estimated combined with the flow rate of cooling water. A self-designed copper mirror with a weakly-reflecting central portion was used to observe the arc behavior in the anode channel. A general digital camera and a video camera were used to record the plasma jet pictures and the arc behavior in the anode channel.

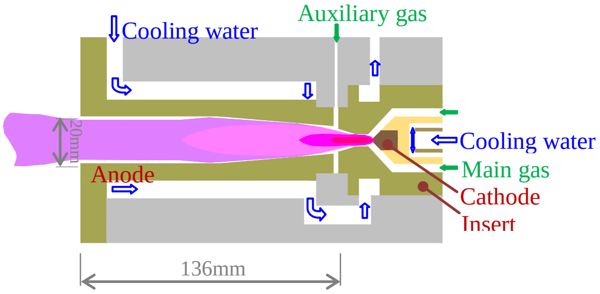

Fig.1 Schematic drawing of the generator structure and working situations.

3. Results and discussions

Gas pressure in cathode cavity of the generator increased with the increasing main gas flow rate of nitrogen, as shown in Fig.2. The “cold gas” in Fig.2 is the situation that no plasma ignited and no auxiliary gas was fed from the downstream of the inter-electric inserter. There was nitrogen or argon and or air gas was fed form the auxiliary passage when the plasma was ignited at a set arc current. Results in Fig.2 indicate that the arc heating at different arc current up to 300 A appears weak effect on the pressure increase in the cathode cavity. This would be caused by the combination effect of small restrictor passage and high gas flow rate which could compress the arc column intensely when the arc passed through the restrictor.

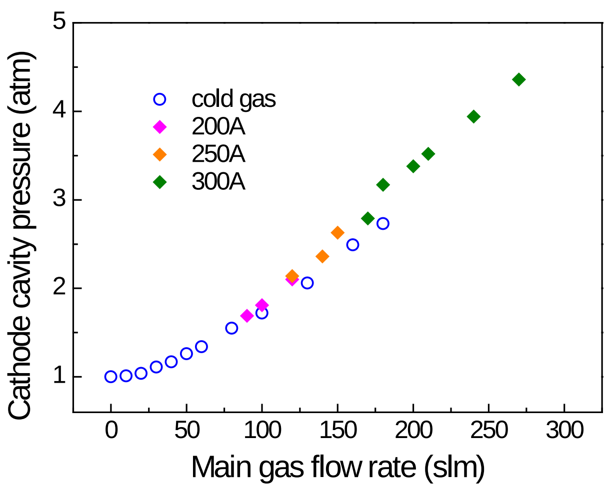

Fig.2 Pressure in the cathode cavity changed as the main gas flow rate of nitrogen at different arc current for plasma igniting.

Gas flow rate and arc current all affected the variation of the arc voltage. Figure 3 shows the arc voltage increased with the increasing gas flow rate of pure nitrogen at different arc current. It seems that the gas flow rate affected the arc voltage change more evidently at high arc current.

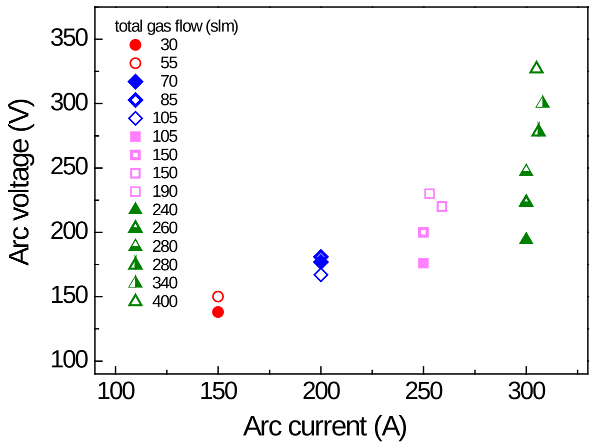

Fig.3 Arc voltage changed as the change of total nitrogen flow rate at different arc current.

Air arc showed similar behavior as that of nitrogen arc. Fig.4 indicates that the arc voltage increased with the increasing total gas flow rate for air plasma, at arc current 200 A and 250 A. Arc voltage of the air arc was slightly higher than that of nitrogen plasma when they were generated at the same flow rate and arc current, comparing the results shown in Fig.3 and Fig.4. Figure 5 shows separately the effect of main gas flow rate or auxiliary gas flow rate on the arc voltage when another gas flow rate and arc current were remained unchanged. It indicated that the air flow rate of main or auxiliary gas had almost the same effect on the arc voltage in the range of experimental parameters.

Ignitions were conducted with different gas type in the order of nitrogen-main/argon-auxiliary, nitrogen/nitrogen and air/air, with the same generator without the change of electrodes. After about 20 min ignition for each set of gas type and working parameters, pictures were taken to see of the anode erosion situation. There was a very slightly erosion could be seen by the surface etching or evaporation of the anode when argon was used as the auxiliary gas, as show in Fig.6 a). This suggests that the nitrogen arc column was fully dispersed in the inserter channel and the argon gas is in favor of the diffused attachment of arc root on the anode surface. Slight screw

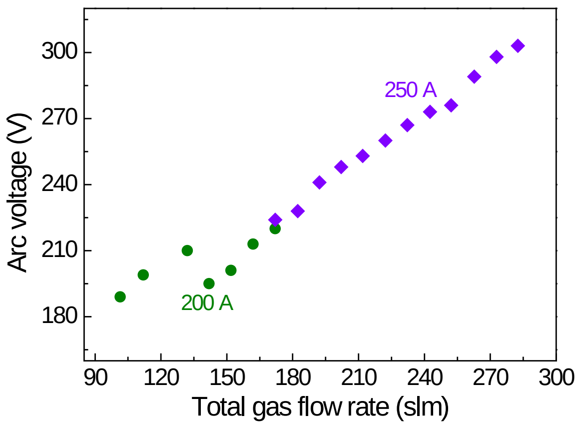

Fig.4 Arc voltage changed with the total gas flow rate of nitrogen at 200 A and 250 A.

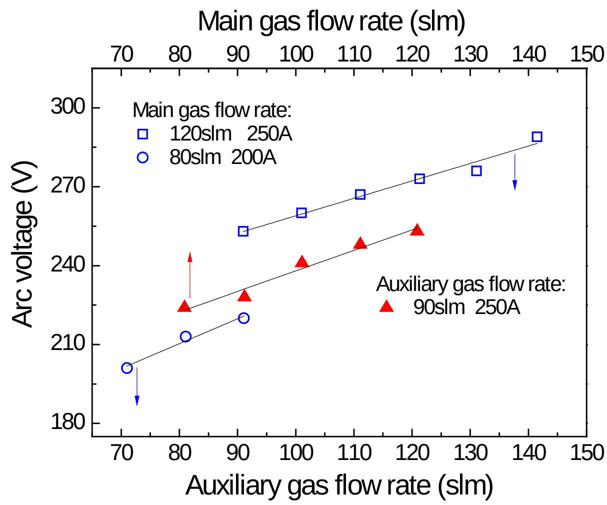

Fig.5 Arc voltage changed with the main or auxiliary gas flow rate of air at set another gas flow rate and arc current.

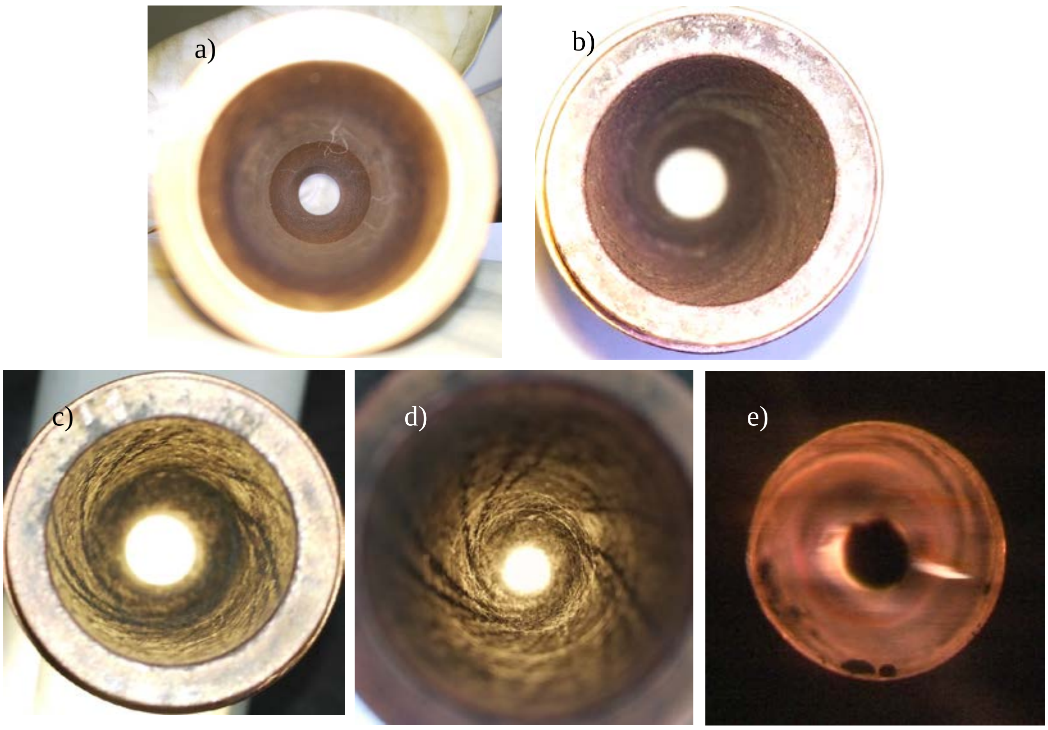

Fig.6 Pictures of the anode channel surface after the ignition, a) N_2-main/Ar-auxiliary gas, b) N_2/N_2 gas, c)-d) air/air gas. e) during the ignition of air/air with the cupper mirror reflecting and camera exposure time of 250 μs through a filter of 1% transmittance.

erosion traces can be seen after the N_2-main/N_2-auxiliary gas ignition, shown in Fig.6 b). This means that the fully dispersed nitrogen arc column was rearranged by the cold auxiliary nitrogen gas fed tangentially from several entrance passages. But the erosion was slighter and much uniform than the general situation at arc current over 300 A. Screw erosion traces can be clearly seen almost on the whole anode surface after the ignition under the air-main/air-auxiliary condition, as shown in Fig.6 c). However, it is still superficial erosion trace indicated by the artificial circular scratch in Fig.6 d), but no any deep erosion trace. Figure 6 e) shows the picture taken by the video camera during the plasma ignition, which corroborated the screw moving and attachment of the arc behavior in the anode channel.

Thermal efficiency of the generator could be over 70% for all the gas type in the experimental range of high gas flow rate condition.

4. Summary

Results showed that the structure of the inter-electric inserter could disperse the arc sufficiently, and the auxiliary gas feeding situation including the gas type and inlet form could affect the dispersed arc condition and hence affect the attachment mode of the arc on the anode surface. Arc voltage increased apparently with the increasing gas flow rate. No deep local erosion could be observed on the anode surface in the working parameter range.

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Reference

[1] Sun X, Heberlein J V R, Fluid dynamic effects on plasma torch anode erosion, Journal of Thermal Spray Technology, 2005, Vol.14 (1): 39-44

[2] Schein J, Zierhut J, Dzulko M, Forster G, Landes K D, Improved plasma spray torch stability through multi-electrode design, Plasma Physics, 2007, Vol. 47(7): 498 -504.

[3] Pan W X, Chen L W, Meng X, Zhang Y, Wu C K, Sufficiently diffused attachment of nitrogen arc by gasdynamic action, Theoretical and Applied Mechanics Letters, 6 (2016) 293–296.

[4] Pan W X, Meng X and Wu C K, Nitrogen and hydrogen arc behavior in a divergent channel, 21th Inter. Conf. on Gas Discharges and their Applications, Nagoya 11-16 Sept. 2016, pp29-32.

[5] Wenxia Pan, Heiji Huang, Lewen Chen, Yong Zhang, Diffused attachment of nitrogen and argon arc root on anode surface by gasdynamic action, 23rd Inter. Symposium on Plasma Chemistry, July 31th to August 4th, Montreal, 2017, pp 732-735,.