A THERMIONIC CATHODE WITH DIFFUSED ARC ROOT FOR PLASMA GENERATORS

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ABSTRACT: A kind of thermionic cathode aimed at achievement of a diffused-arc-root mode of operation is described in this paper. The ceria-tungsten cathode has a hollow construction, and the arc root is attached to the inside of the cavity. It rotates at high speed under the action of the tangential gas flow and the axial magnetic field. Thus, compared to the usual type of solid conical or button-type cathodes, it has a larger area of arc root attachment and should result in lower current density. The arc characteristics of a plasma generator using this type of cathode with various dimensions of the cavity and gas flowrate through it, different gas media, presence or absence of applied magnetic field, etc. are presented. The flowfield and temperature distribution inside the plasma generator were computed numerically.

INTRODUCTION

In DC arc palsma genertors with thermionic cathodes, refractory metals such as thoria-tungsten, ceria-tungsten, zirconium and hafnium are often used as cathode materials. The arc root may either be constricted or diffused, depending on the gas pressure and type of gas, arc current, cathode material, condition of cooling, etc. Some recent research works on this subject are represented by [1, 2]. The constricted type of arc root is characterized by a bright spot on the cathode surface with very high current density which may reach 10^4–$10^5 A/cm^2$, high surface temperatures, and high heat flux within the spot. Thus the material within the cathode spot can easily reach its melting or boiling point, and high rates of erosion are generally unavoidable at high currents. On the contrary, the diffused type of arc root is not characterized by a bright cathode spot, and the current density and heat flux are lower, so are the surface temperatures and erosion rates. Since electrode erosion is an important problem in high power plasma generators, the study of the modes of operation of cathode arc roots and their control have always been of interest.[3,4]

In thermionic cathodes operating under atmospheric pressure, the constricted mode of arc root is generally encountered. Some research to obtain diffused arc root under atmospheric pressure has been carried out with various degree of success. Some used the method of injecting small quantity of vapor of easily ionized elements such as Na or K into the near cathode region [5]. Or the cathode can be preheated more or less uniformly to the emission temperature [6]. In this paper, some preliminary investigation on an attempt to achieve diffused arc root on thermionic cathode using special construction and operational methods of the cathode is described.

BASIC CONSIDERATIONS FOR DIFFUSED ARC ROOT

Thermionic emission of the cathode material can be described by the Richardson-Dushman equation. For a given material, the current density of electronic emission at the surface is mainly determined by the surface temperature. If a large enough area of uniformly high temperature can be maintained on the cathode surface so that enough electrons can be emitted more or less evenly at a relatively low density from the surface, then a diffused arc root may be achieved.

The surface temperature of the cathode is determined by the energy balance at the cathode surface, which is expressed by the equation:

$$I_i(u_K + u_i) + q_R + q_H = I_i\phi + I_e\phi + q_m + q_e + q$$

where the first term on the left hand side represents energy transported per unit time to the cathode surface by the ion current, q_R the energy transport by radiation from the arc, q_H the heat transfer other than radiation from the plasma to the surface. The terms on the right hand side represent respectively the electron work function, the heats of fusion and vaporization, and the heat conducted to the interior of the cathode material. Heat to the cooling water is the sum of heat conducted and the Joule heating in the material. Solution to the heat balance equation gives the surface temperature distrubution.

The ordinary button type cathode is a cylindrical refractory metal piece embedded in a water-cooled base, as shown in Fig. 1a. In this case, the temperature distribution is axially symmetric, with the highest temperature at the center. Therefore, the current concentrates toward the center, and usually the arc root is of the constricted type. The self-magnetic field of the arc near its root is also an important factor in the constriction of the arc root.

We have tried a hollow thermionic cathode as shown in Fig. 1b. Under the action of tangentially flowing gas and magnetic field, the arc root rotates at high speed and enters the cavity to a certain depth. In this case, the heat transferred to the cathode surface is more or less uniform over the circumference of the inside surface. Thus the surface temperature would be more uniform over a larger area, and a diffused emission of electrons may result.

EXPERIMENTAL RESULTS

The experimental installation is shown schematically in Fig. 2. The cathode is a ceria-tungsten piece with a cavity. The anode is copper. The cathode is located in a magnetic field of 0.02T, produced by a d.c. supplied coil. A narrow passage between the cathode and anode provides tangential inlet gas flow. A stream of gas is also passed into the cavity from the rear end. There are two factors which cause the arc root to enter the cavity. The first is the flow pattern of the gas, which is similar to the tubular arc heaters, with an upstream component (secondary flow) of the rotational inlet gas near the entrance to the cavity. The second is an action of the radial component of the applied magnetic field on the rotating arc, which causes the arc root to move towards the center of the magnetic field when the wall is the cathode. An analysis of this phenomenon based on motion of charged particles in a magnetic field is given in [7].

We have experimented with two cavity diameters, two kinds of gases, various internal gas flow, and with or without magnetic field. The measured quantity is mainly the volt-ampere characteristics, which can also indicate the way the arc root is attached to the cathode. The observation of the trace of the arc root indicates that higher voltage generally corresponds to deeper position of the arc root inside the cavity. The arc traces show that the arc root is spread out uniformly over a certain width of the inner circumference of the cavity.

Fig. 3 shows the volt-ampere characteristics of the arc under various conditions. Curve 2 (gas to cavity = 100L/h) is lower than curve 1 (no gas input to the cavity from the rear). Curve 4 (solid cathode in Argon) is lower than curve 3 (cathode with cavity). Fig. 4 shows the relationship between cavity gas flow and arc voltage, the voltage decreases with increasing cavity gas. Fig. 5 shows that arc voltage increases with increasing magnetic field, the voltage evidently higher with the magnetic field. Observation of the arc root trace show that the depth of arc root in the 6mm dia. cavity is greater than in the 3mm dia. one. All these observations agrees qualitatively with our understanding of the actions of gas flow and magnetic field on the arc root [7].

NUMERICAL COMPUTATION OF THE FLOWFIELD

For a better understanding of the flowfield inside the plasma generator, a numerical simulation was performed. The assumptions were:

(1) An axially symmetric two-dimensional flow model was assumed
(2) The plasma was in LTE
(3) The flow was laminar (small size, high temperature)
(4) Viscous dissipation and gravity were neglected
(5) The plasma was optically thin
(6) Magnetic fields were not considered

The conservation equations with the proper gas properties and boundary conditions were solved numerically with a finite difference scheme.

The flow and temperature fields with different cavity gas flow are shown in Fig. 6-9. Fig. 6,7 are those with 0 cavity gas flow, and Fig. 8,9 are those with 50L/h cavity gas flow. It is seen that the flow field can be affected by the cavity gas so that the position of the arc root can be controlled to a certain extent.

DISCUSSION

With a cathode and plasma generator structure as described in this paper, the cathode arc root can be made to attach to the inside of the cylindrical cavity and rotate rapidly under the action of the tangentially flowing gas and the magnetic field. The movement of the arc root heats the inside surface of the cavity more uniformly, producing a larger area of uniformly high temperature, thus enabling the formation of a diffused arc root. In [8], a similar cathode construction was used for axial powder injection in spraying studies, and it was concluded that heating to the powder was much improved and better sprayed layer was obtained.

For high currents, the cathode with cavity and with small amount of argon gas passed from the rear end is a promising type. The current density may be reduced and the electrode life may be lengthened.

The control of arc root coverage by gas flow and magnetic field in the cavity of the thermionic cathode is an interesting subject on which we will do more study.

ACKNOWLEDGEMENT

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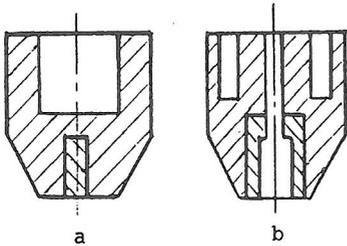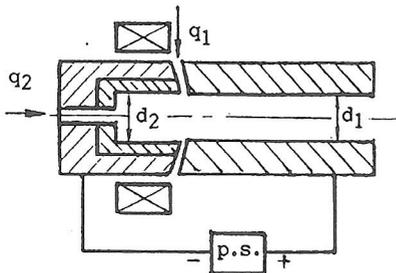
Fig.1 Schematic diagram
of cathodes

Fig.2 Schematic diagram of
the plasma generator
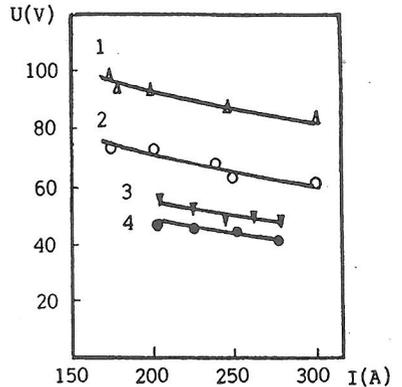

Fig.3 V-I characteristics of
the plasma generator

1 q_1=1500L/h, q_2=0, d_1=5mm, d_2=6mm, N_2
2 q_1=1300L/h, q_2=100L/h, d_1=5mm,
   d_2=6mm, N_2
3 q_1=1500L/h, q_2=0, d_1=5mm, d_2=3mm, Ar
4 q_1=1500L/h, q_2=0, d_1=5mm, d_2=0, Ar
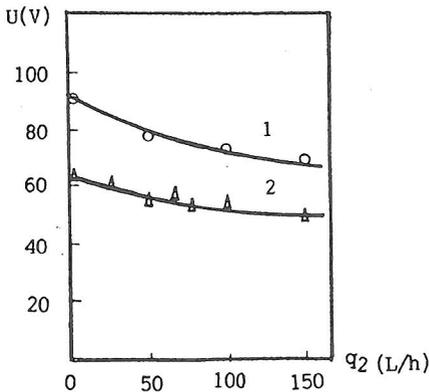
Fig.4 Relation between q_2 and U

1 q_1=1500L/h, I=200A, N_2
   d_1=6mm, d_2=6mm
2 q_1=1800L/h, I=220A, Ar
   d_1=6mm, d_2=3mm
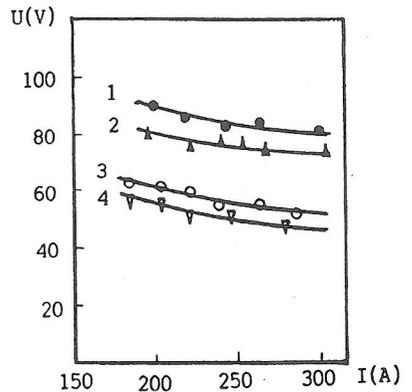
Fig.5 V-A characteristics of
the plasma generator

   d_1=6mm, d_2=3mm
1 N_2, q_1=1500L/h, q_2=0, B=0.02T
2 N_2, q_1=1500L/h, q_2=0, B=0
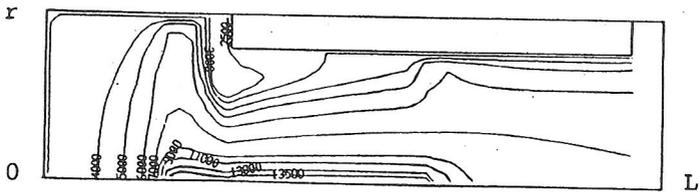3 Ar, q_1=1800L/h, q_2=0, B=0.02T
4 Ar, q_1=1800L/h, q_2=0, B=0

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Fig.6 Isotherms in the generator
I=100A, N_2, d_1=5mm, d_2=6mm, q_1=1300L/h, q_2=0
r--radius of cathode, L--length of generator
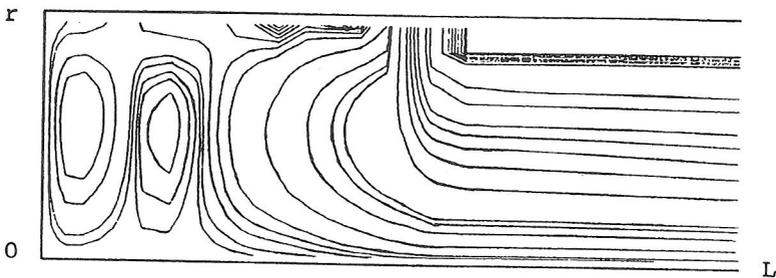

Fig.7 Streamlines in the generator
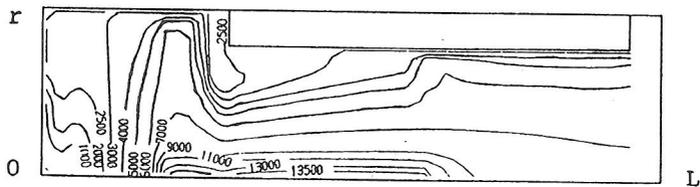I=100A, N_2, d_1=5mm, d_2=6mm, q_1=1300L/h, q_2=0

Fig.8 Isotherms in the generator
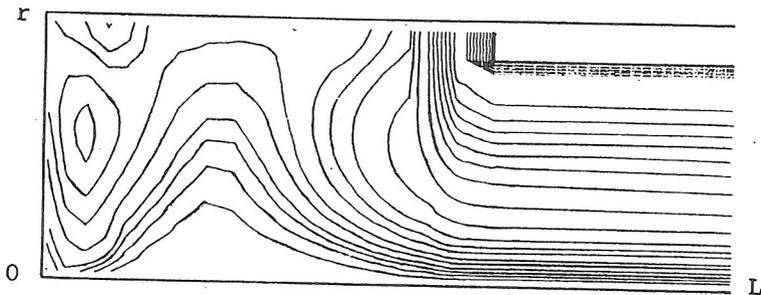I=100A, N_2, d_1=5mm, d_2=6mm, q_1=1300L/h, q_2=50L/h

Fig.9 Streamlines in the generator
I=100A, N_2, d_1=5mm, d_2=6mm, q_1=1300L/h, q_2=50L/h