Angular distribution of charged and neutral species in vacuum arcs

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I.5 ELECTRODE PHENOMENA

ANGULAR DISTRIBUTION OF CHARGED AND NEUTRAL SPECIES IN VACUUM ARCS

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Abstract

Experimental results are presented showing the existence of two dominant mass flows in a vacuum arc. Ions are mainly directed perpendicular to the cathode plane; their angular flow agrees with a cosine distribution. Neutral mass is expelled along the cathode plane in droplet form.

INTRODUCTION

In a vacuum discharge charged and neutral species are present. Both are formed in and near the cathodespots, but there's still uncertainty about the direction in which they fly away from these spots.

Plyutto et al [1965] state that the maximum density of the ions is found in a direction perpendicular to the cathode plane, while most neutrals are escaping under a small angle with the cathode surface. Kutzner et al [1970] however demonstrate the existence of two dominant streams of neutral mass flow in these directions. Finally Kimblin [1971] found an isotropic distribution for both ions and neutrals. Experiments have been undertaken to determine the angular distribution of ions and neutrals in a vacuum discharge.

DISTRIBUTION OF IONS

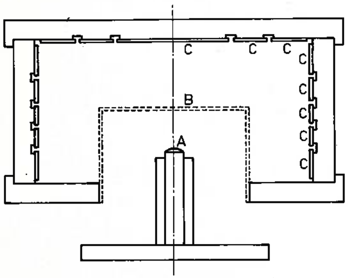

Fig:1 Experimental arrangement for ion flux measurements. A=copper cathode. B=wire cage anode. C=ion collector shields.

For the determination of the distribution of the ions, a cylindrical construction as drawn in fig. l has been used. The cathode A has been made of spectroscopically pure copper and has a diameter of 5 mm. To prevent the arc from wandering down along the electrode, the cathode stem is surrounded by a ceramic collar.

The current due to ions moving in different directions is detected by a set of eight cylindrical collector shields placed behind the anode. They are biased to cathodepotential via 1 ohm measuring shunts. To give the ions in all directions an almost equal chance to reach the plates behind the anode, the anode consists of a grid of stainless steel. For species moving perpendicular to this grid, the transmissioncoefficient is 63%. The whole construction is placed in a steel cylinder with a pressure less than 10^{-7} torr.

One kind of angular distribution of the ion current that was found agrees fairly with a cosine law ("C" in fig. 2), with an exception for small angles with the cathodeplane. This is probably due to slight instability of the arc.

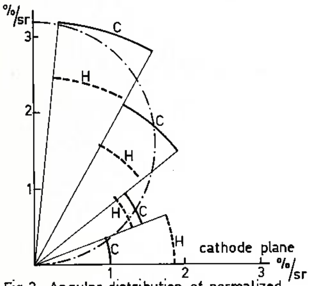

Fig:2 Angular distribution of normalized ion current flow $\frac{1}{I_e}\frac{\Delta I_i}{\Delta\Omega}$

Fig. 2 shows the angular dependency of ion current ΔI_i, divided by the solid angle subtended by the shields at the centre of the cathode $\Delta\Omega$ and the total arc current I_e. The unit of this normalized variable is percent per steradian (%/sr.). For a cosine distribution and a total ion current of 10% of the arc current (dotted line in fig. 2), the value on the axis should be 3,2%/sr., which is close to the measured value. Distributions like C of fig. 2 have been found for arc currents of 50, 80-100, and 140 A.

Another kind of distribution, measured with this set-up under identical circumstances is characterised by having a lower ion current along the system axis, and a higher ion current in the cathode plane if compared with distribution C ("H" in fig. 2). Some measured distributions seem almost homogeneous. This result can be explained by surface irregularities, spot movement and/or burning of the spot on the cathode edge which causes the axis of the cosine distribution to rotate with respect to the axis of the measuring system. This leads to a disturbance of the cylindrical symmetry so that each ion collector sheet now receives ions of different angles which means that the distribution actually measured becomes more homogeneous.

Although the measurements, made with this set-up showed variation in the distributions obtained, from these results the conclusion can be drawn that the current density of the ions has a maximum along the axis of the system and probably agrees with a cosine distribution. To compare these experiments with ones, made earlier, the total ion current - after correction for the transmissioncoefficient of the anode - has been calculated. The values found were between 9 and 11% of the discharge current which is somewhat higher than the 8% found by Kimblin [1971].

DISTRIBUTION OF NEUTRALS

The angular distribution of the neutral mass leaving a copper cathode was investigated by using an anode and a cathode which were 10 mm and 25 mm in diameter respectively. The electrodes were surrounded by a stainless steel cylinder (fig. 3). A 140 A d.c. arc was drawn and burned during 80 msec. in an electrode gap of 10 mm. This procedure was repeated 50 times. The total mass loss of the cathode hereafter was 42,5 mgr. For an ion current which is 10% of the discharge current and if the ions have an average charge number of 1,8 (Davis and Miller, 1969) the mass loss in charged form is 19 mgr. The amount of mass loss in neutral form therefore is 23,5 mgr.
Inspection of the shield showed numbers of particles varying in size from less than 1 μm up to 70-100 μm diameter. This number is largest at a small positive angle ($\phi = 4^{o}$) with the cathode plane. For increasing angles (positive and negative) the particle density rapidly decreases, this being specifically true for the larger particles (fig. 4). The volume of the particles was determined by interferometry. Calculation showed the amount of mass represented by these particles in a region of $0<\phi<20^{o}$ to be 20,8 mgr which is 89% of the amount of neutral mass lost by the cathode.
The cathode mass loss of neutral species therefore is mainly as particles ranging in size from 1 to 100 μm. The flow of these particles is restricted to small angles with the cathode plane (cf. Plyutto et al, 1965).

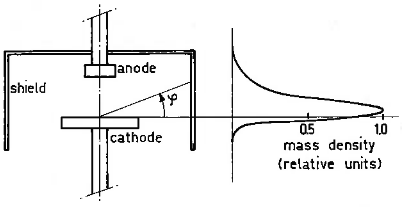

Fig:3 Arrangement to determine neutral mass flow from the cathode and relative mass density of particle deposit on the collector shield.

Previous experiments (Daalder, 1975) showed the amount of neutral mass per unit charge leaving the cathode to be dependent on different variables as charge transfer, cathode size and/or velocity of the cathode root(s).
The ion mass per unit charge however was not a function of these parameters. Under specific conditions the total mass loss suffered by the cathode is almost entirely due to charged species i.e. the cathode erosion has a lower limit.

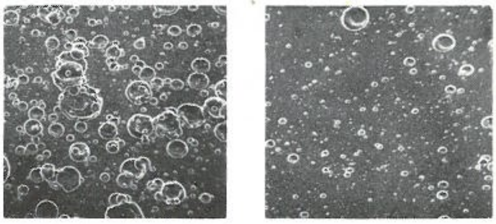

Fig:4 a Fig:4 b

Comparison of particle density on the shield at an angle of $\varphi=4^{o}$ (Fig: 4 a) and $\varphi=20^{o}$ (Fig: 4 b).

It was demonstrated that these data can be explained by a model of a metal vapour discharge which is fully ionized; the ions being generated in the cathode spot(s) proper while neutrals are formed in the vicinity of these spots.

The measurements presented here support this idea. The neutral mass loss being largely in droplet form indicates temperatures around the melting point of the cathode metal which is likely for areas directly surrounding the high temperature cathode spots.
The preference of the droplets to move at small angles with the cathode plane may be due to large pressure gradients existing at the boundaries of the expanding ion streams, which originate from these spots.

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