Influence of Magnetic Fields on Anode Losses in MPD-Arcs

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Theme

THE application of high-magnetic field-strengths in Hall current accelerators in some cases leads to extremely severe heat losses at the anode. Therefore, the behavior of the anode losses under the variation of magnetic field-strength and shape, background pressure, mass flow rate and arc current was investigated experimentally. The various origins of the losses (gasdynamic, current transfer etc.) are identified in order to relate them to more pertinent variables. Finally, an attempt is made to qualitatively explain the observed behavior.

Contents

All experiments were carried out with a continuously operating MPD-accelerator according to Fig. 1 and with argon as feed gas. The water cooled anode cylinder has an inner diameter of 60 mm and is axially divided into 4 independent ring segments. The second-most downstream ring served as the real anode while the others remained floating. Two thruster configurations were considered. In the open configuration the anode cylinder is freely suspended so that the tank environment can act on the arc column between the two electrodes. In the closed version the column is completely separated from the tank environment. Two magnetic coils provide a field of arbitrary shape and strength. The ratio Λ of their respective currents describes the field-shape: For $\Lambda = 3\frac{1}{3}$ the fieldlines are parallel to the anode surface and divergent for $\Lambda < 3\frac{1}{3}$. The heat loss $Q(kW)$ to the 4 ring segments was measured. Because Q is only of gasdynamic origin in the floating rings, an interpolated value may be subtracted from the loss Q_A of the anode ring to find the fraction due to the transfer of current. The electric potential of all rings was measured. This allowed the definition of an anode fall voltage V_A as the difference between the arc voltage and the interpolated value of the floating voltage. The static surface pressure near the anode was measured relative to the ambient tank pressure.

In the paper it is shown that Q_A grows linearly with the anode fall voltage V_A. For all interesting cases, the rest of the losses are small enough to justify a discussion of the loss behavior by looking at V_A only. Figures 2 and 3 show the most important directly measured results.

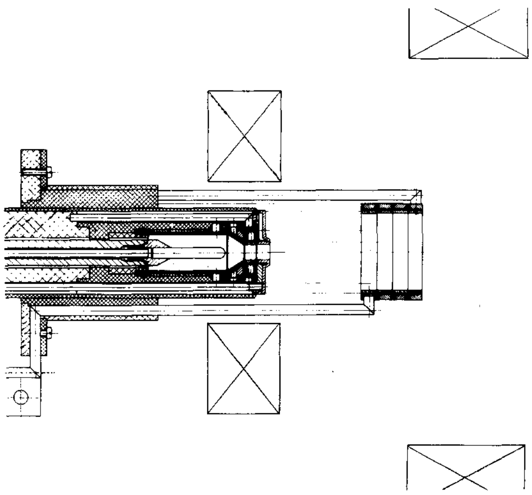

Fig. 1 Experimental accelerator with segmented anode cylinder.

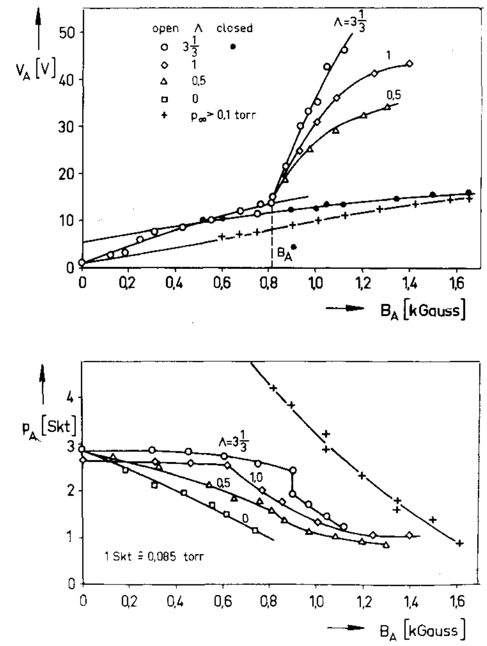

Fig. 2 Variation of the anode fall voltage and anode pressure with the magnetic field (300 amp, 0.5 g/sec, $p_\infty < 0.1$ torr).

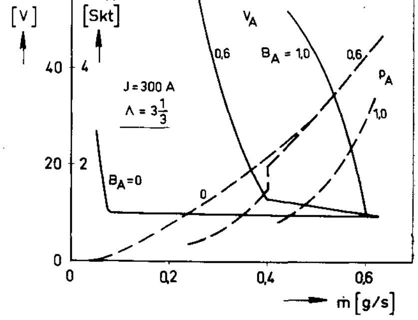

Fig. 3 Variation of the anode fall voltage and pressure with mass flow for parallel fields of different strengths ($p_\infty < 0.1$ torr; open arc).

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1) For the open configuration, two ranges exist in ambient pressure p_∞ with different loss behavior. With $p_\infty > 0.1$ torr the anode voltage remains low for all magnetic field-strengths B_A at the anode, as do the losses. Independent of p_∞, they account for approx. 30% of the input power at 300 amp arc current and a mass flow rate of 0.5 g/sec. They also show no dependence on the magnetic field. The closed arc device exhibits this behavior for all values of p_∞.

2) With $p_\infty < 0.1$ torr in the open configuration the high-pressure behavior is duplicated only up to some critical field-strength, corresponding to mass flow and current. From this point on the anode heat losses are increased abruptly because of a sharp rise in anode voltage. Here, they can account for more than 50% of the arc power. At $V_A \approx 50$ v the arc ceases to operate properly and the anode is eroded. As seen in Fig. 2, the rise in V_A now shows a strong dependence on the field-shape. Along with the increase in anode voltage a drop in the surface pressure p_A is observed.

3) If the mass flow $\dot{m}$ is reduced and the magnetic field held constant, there also exists a critical value below which the anode fall increases. For zero magnetic field this is well known.[1] But as Fig. 3 shows, even for medium field-strengths the critical mass flow is significantly increased (up to 0.6 g/sec at 1 kgauss). Again, a change in field-shape does not influence the critical value but rather the rate of increase in fall voltage. The pressure curves show a shift towards lower values for higher magnetic fields, which indicates that part of the mass flow is removed from the vicinity of the anode surface.

These results are concluded to be a consequence of several related mechanisms. An increasing magnetic field reduces the current conductivity perpendicular to the fieldlines. The resulting electromagnetic forces lead to a mass concentration along the axis. At a given mass flow this happens on the expense of a particle depletion in the outer plasma regions, i.e., at the anode. Finally, the arc can maintain the current transfer only with the help of an additional force field for the electrons, which appears as an intensification of the anode fall.

Studies were made to find a correlation between the anode fall growth and the parameters p_A and B_A. A V_A/B_A-diagram was derived with the anode surface pressure p_A as parameter. Figure 4

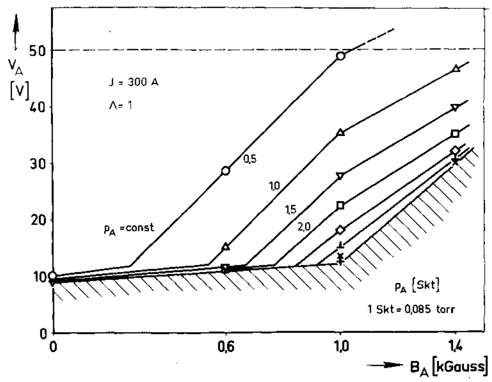

Fig. 4 Variation of the anode fall voltage with anode field-strength and pressure at the anode ($p_\infty < 0.1$ torr; open arc).

shows that for increasing p_A the curves approximate a limiting curve. For higher magnetic fields the minimum possible anode fall is a strong function of B_A. Other findings confirm that the required anode pressure for lowest V_A has an exponential type increase with the magnetic field-strength. The conclusion is that for high field-strengths a certain anode fall and with it a certain anode loss cannot be prevented by choosing a higher pressure at the anode. However, a higher pressure is at least capable of reducing the anode voltage to its lower limit. This has been demonstrated by adding mass at the anode in another thruster.[2,3]

References

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[2] Krülle, G., "Fortführung der Arbeiten an MPD-Triebwerken," *DLR Mitteilung 71-21, Bericht über das DGLR-Symposium Elektrische Antriebssysteme*, Teil 1, Oct. 1971, pp. 283–298.

[3] Kurtz, H., "Integrale Messungen an einem axialsymmetrischen, elektromagnetischen Plasmabeschleuniger," Diploma thesis, Aug. 1971, Univ. of Stuttgart, Germany.