A STUDY OF A CUSP-ENHANCED DUOPIGATRON ION SOURCE

M.R. Shubaly
Atomic Energy of Canada Limited, Research Company
Chalk River Nuclear Laboratories
Chalk River, Ontario, Canada K0J 1J0

Summary

The effects of adding multipole magnetic-cusp confinement to the duoPIGatron plasma generator in high current ion sources is being studied. Axial cusps with multiplicity varying from four to sixteen are being studied, as are ring cusps with multiplicity ranging from two to five. For the axial cusps, plasma generator efficiency improves as the multiplicity increases; however even at high multiplicity it is not as good as without cusps. The uniformity also improves with the number of cusps, becoming equal to that of the simple duoPIGatron with a multiplicity of ten. This paper presents the results of measurements on the various configurations.

Introduction

This study was undertaken to determine the effect on ion species ratio and arc efficiency of adding various magnetic multipole configurations to a duoPIGatron plasma generator. Also of interest was the effect on plasma uniformity at the extraction plane. It was expected that multipole geometries, because of their improved confinement of electrons, would provide higher efficiency and better uniformity.

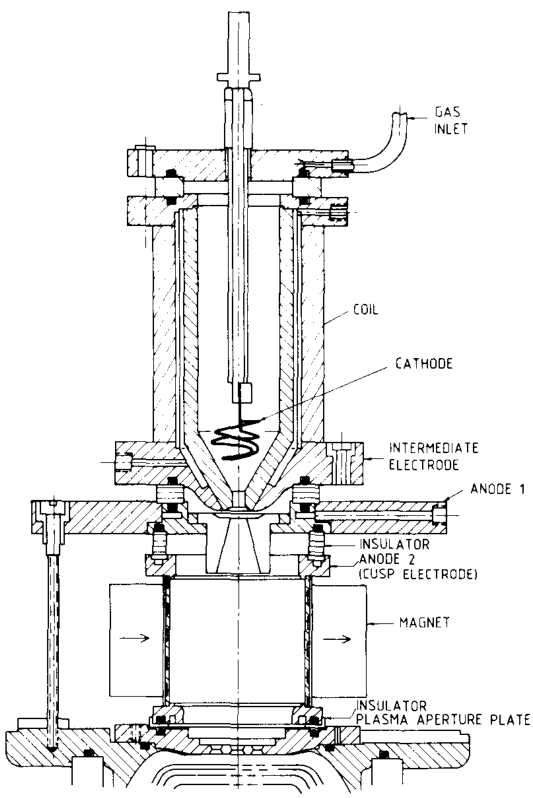

Fig. 1 Plasma generator arrangement.

The ion source used was a modified version of the high current dc duoPIGatron source under development at Chalk River[1]. Figure 1 shows the plasma generator arrangement. The second anode ring and two large ceramic rings generally used in the reflex (PIG) region of the plasma generator were replaced by two thin insulating rings and a long thin-walled water cooled stainless steel tube of 7.32 cm outside diameter and 6.35 cm inside diameter. The inside diameter and length of the PIG region were unchanged from normal operating values. The extraction array consisted of three in-line 5 mm diameter apertures with a centre to centre spacing of 7.6 mm and with the centre hole of the array on axis. The rest of the plasma generator and the extraction column were unchanged from their normal configuration. The multipole arrays were attached to the plasma generator with non-magnetic clamps - no return yoke was used. For the ring-cusp measurements, mild steel rings were used as pole-pieces as shown in Fig. 2.

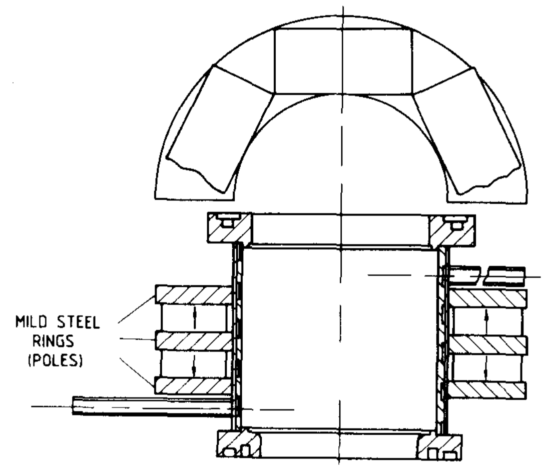

Fig. 2 Ring cusp arrangement.

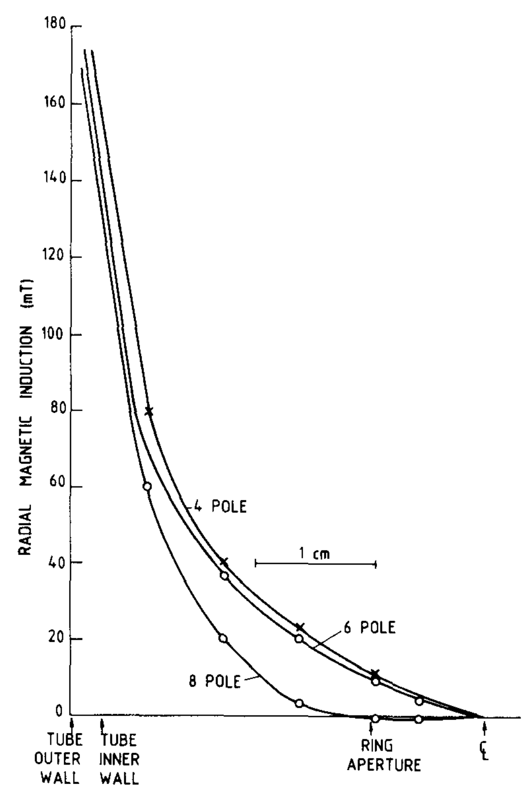

Fig. 3 Radial magnetic induction profiles for 4, 6 and 8 pole axial cusps.

Plasma uniformity was judged by visual inspection of the beam 40 cm downstream from the extraction column where the beamlets are still well separated. The extraction voltage was varied to give beamlets with the best defined edges. From past experience, current variations, beamlet to beamlet, of less than 10% can be detected by comparing the edge definition. Ion species ratio measurements were made on axis by magnetically analyzing a small fraction of the beam passing through a slit in the beam stop.

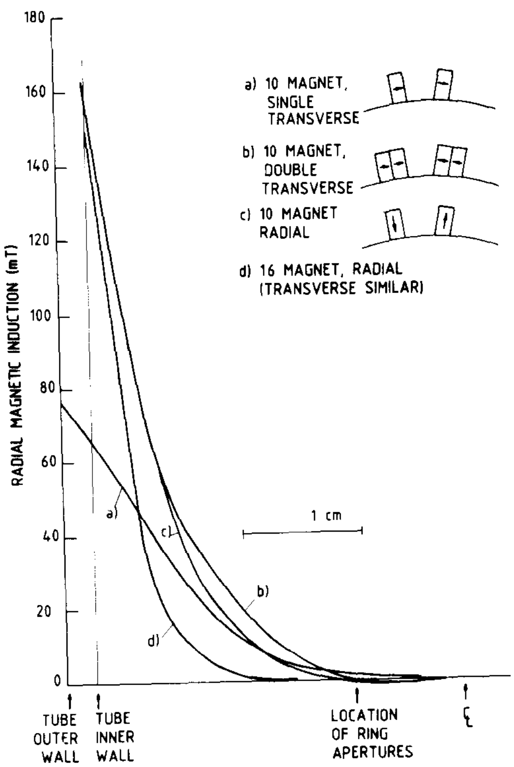

Fig. 4 Radial magnetic induction profiles for different 10-pole cusp arrangement, and for a 16-pole cusp.

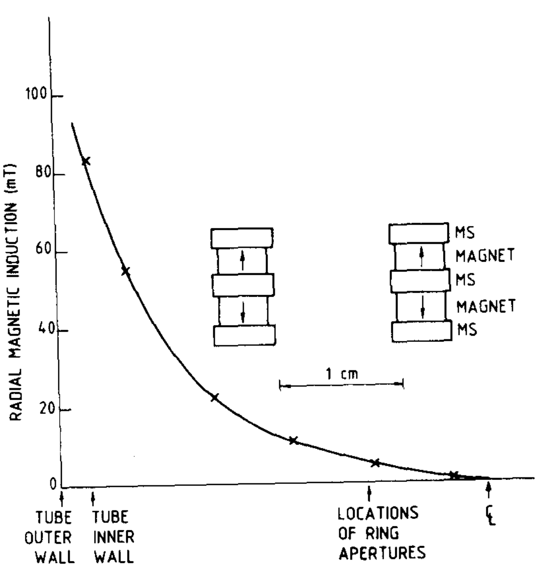

Fig. 5 Radial magnetic induction profile for 3-pole ring cusp.

Measurements and Discussion

Magnetic field maps were made on semi-cylindrical sections of the arrays and on the lines of maximum field for the axial cusp arrays (see Fig. 3 and 4). Magnets were selected to have field variations, magnet-to-magnet, of less than 5%. The field dropoff is much more rapid with the higher multiplicity, as expected. However, for all cases, the induction at the aperture is small (< 2 mT) and about equal to the induction from the compressor coil in normal operation. Figure 5 shows similar measurements for a three-pole ring-cusp. In this case, the magnetic induction at the extraction array was less than 1.5 mT.

Figure 6 shows the beam current as a function of arc current for various axial multipole configurations compared to the current when no magnets were used. To achieve reasonable beam current and beam quality with the multipoles higher than normal coil current was required. For a given arc current, the beam current increases as the coil current is increased. However, the emittance of the beam (at fixed beam current) is usually higher if a high coil setting is used. Not only is the arc efficiency much worse with the multipoles, but also the beam quality was very poor. With no magnets, all three beamlets were uniform and very well defined. With the low multiplicity cusps, clear definition of all three beamlets could not be achieved. Even with the 10-pole array, clear definition could only be achieved at high current, and only by adjusting the angular orientation of the magnets with respect to the extraction array to give minimum field at the apertures. Unfortunately, no measurements could be made with the 16-pole array because of interference between the magnets and the water inlet and outlet pipes. There was negligible damage to the tube wall in the regions of the cusp except for the four-pole cusp where there were shallow melted areas along two of the cusps.

Figure 7 shows the effect on arc efficiency of increasing the cusp field. The low field arrangement

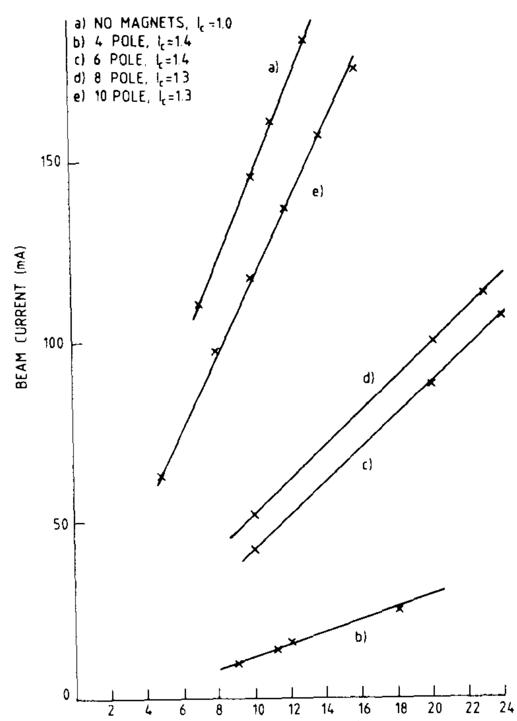

Fig. 6 Beam current as a function of arc current for multiplicities ranging from 4 to 10 compared to beam current without magnets.

corresponds to the induction shown in Fig. 4(a), the high field arrangement in 4(b). Comparing curves a) and c) in Fig. 7, the arc efficiency with the lower field is about twice as high as with the high field. Even operation at higher coil current (curve b) does not match the efficiency of the lower field.

Figure 8 shows the arc efficiency of a three-pole ring cusp. A high coil current and high gas flow were required to achieve stable operation. As with the other multipoles, the efficiency was quite low. This geometry should provide a smooth transition between the axially symmetric field of the intermediate electrode and the cusp and thus reduce loss areas where field lines intersect the anodes. The source would not operate in this configuration unless the polarity of the coil field was opposite to that of the top cusp.

Table 1 shows some of the measured ion species ratios for various configurations. Given that small change in gas flow can lead to variations in the measured fraction of up to 5%, no significant effect on the species ratio with the cusp field was found, whereas the high arc currents needed for the multipoles were expected to give an increase in the proton fraction.

The above results were quite surprising as they contradict some experiments[2]. A possible explanation is that the plasma generator geometry has been optimized to run without cusps.

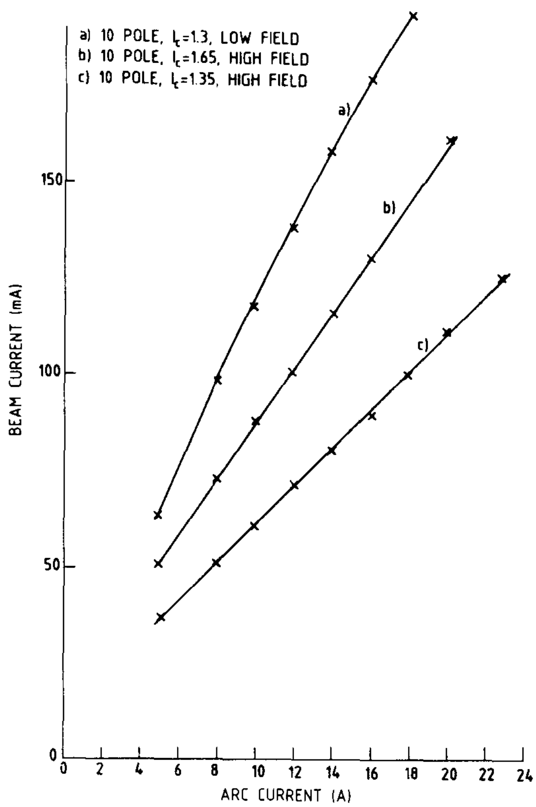

Fig. 7 Beam current as a function of arc current for different 10-pole configurations.

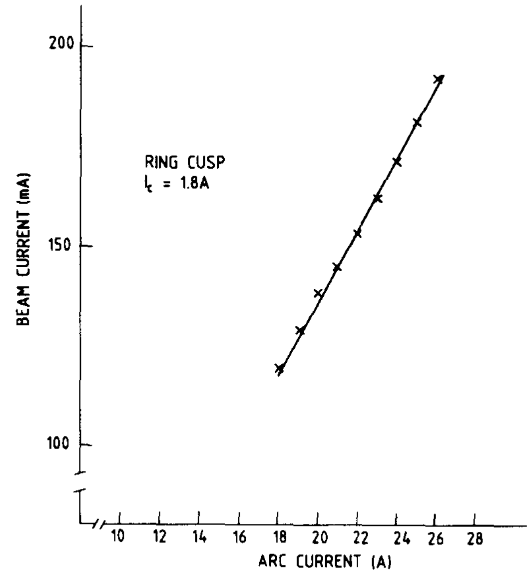

Fig. 8 Beam current as a function of arc current for a three-pole ring cusp.

Table 1

Ion Species Ratios

Configuration	Arc (A)	Coil (A)	Beam (mA)	H_3^+ (%)	H_2^+ (%)	H_1^+ (%)
No magnets	13	1.0	180	24	45	30
4 pole	20	1.4	23	54	11	35
6 pole	20	1.4	88	33	38	29
8 pole	20	1.3	91	37.5	37.5	25
10 pole	12	1.35	150	32	34	34
10 pole	25	1.1	183	24	40	36

Acknowledgements

I would like to thank Richard Maggs for making these measurements and analyzing the data, and for his effort in fabricating the numerous clamping jigs required for these tests.

References

1. M.R. Shubaly and M.S. de Jong, "High Current DC Ion Beams", IEEE Trans. Nucl. Sci., NS-30, 1399 (1983).
2. R. Keller, GSI, private communication.