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HIGH CURRENT DC ION SOURCE DEVELOPMENT AT CRNL

Murray R. Shubaly*

Abstract

High current dc ion sources suitable for use in accelerators are being developed. Two such sources are described - a duoplasmatron source to provide 25 mA dc of deuterons for the Fast Intense Neutron Source (FINS) accelerator; and a duoPIGatron source with a multi-aperture extraction column to produce a 50 keV, 500 mA dc proton beam (∿ 750 mA dc total current). The final design for the FINS source is presented and the factors most strongly affecting source performance are identified. Initial experiments with the high current source (to 450 mA total current) are described. Accurate measurements of beam emittance at various currents are presented.

Introduction

The ion source development program at the Chalk River Nuclear Laboratories has primarily been concerned with high current dc ion sources for accelerator applications. This paper describes two such sources: a medium current duoplasmatron source to provide 25 mA dc of deuterons for the Fast Intense Neutron Source accelerator and a duoPIGatron source with a multi-aperture accel-decel extraction column to provide a 50 keV 500 mA dc proton beam suitable for a 1 GeV 300 mA accelerator for fissile fuel production.

The FINS Ion Source

The Fast Intense Neutron Source (FINS)[1] comprises a 300 kV 50 mA dc accelerator and a tritium-loaded-titanium rotating target to produce 4 x 10^{12} n/s for health physics experiments. The ion source is mounted in a re-entrant can in the accelerator column. Ions are emitted directly into the column. Focusing is produced by a suitably shaped electrode (focus plate) on the face of the can and by varying the total acceleration voltage. No separately adjustable focus electrode is used. The required deuteron current is 25 mA dc with total ion current to be less than 45 mA. Because all ions produced in the source are accelerated, the fraction of molecular deuterons and heavy ions was to be minimized. Because room activation by the high neutron flux during operation limits access to the accelerator, long source life and good reliability were required. Furthermore, source changes should be readily accomplished.

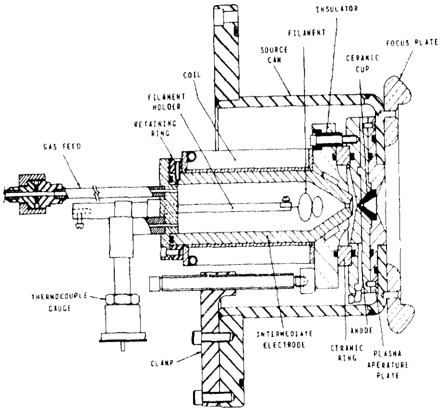

Fig. 1 FINS Ion Source

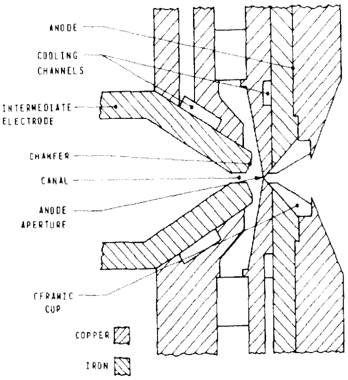

Fig. 2 FINS Ion Source Internal Geometry

Figure 1 shows the source mounted in the source can. Cooling has been improved to cope with the high heat loads incurred in dc operation. Refinements in the internal geometry of the source have given a 3-fold increase in the beam current available for given arc power. The shaped ceramic expansion cup reduces beam emittance. A Moak[2] filament is used because the Wroe[3] filament, although having a longer life in most cases, was found to be very susceptible to poisoning by minute amounts of SF_6 that leaked into the system. Filament power is approximately 125 watts. The compressor coil provides up to 3000 ampere turns. Figure 2 is a detailed view of the critical intermediate-electrode and anode region and of the extraction region. The cooling channels in the anode and the intermediate electrode are necessary to reduce erosion of the apertures in these parts. The dimensions of the intermediate electrode nose have been chosen to give maximum beam current consistent with good starting. Reduction of the canal diameter or of the depth of the chamfer increases beam current but arc transfer to the anode is inhibited. The anode is a copper-iron sandwich to provide good cooling and a properly shaped magnetic field in the anode aperture region and to decrease the magnetic field in the ceramic expansion cup and accelerating column. The anode aperture of 0.46 mm was chosen to reduce gas flow in the source. High current operation with increased gas flow is possible by increasing the anode aperture diameter up to 0.66 mm before beam quality is degraded. If the land on the anode aperture is much larger than the 0.05 mm design value the beam current is decreased. Conversely a reduction in this land dimension leads to rapid erosion of the aperture. With the design shown, anode lifetime is greater than 100 hours. In the FINS accelerator the major source of damage to the anode is erosion by backstreaming electrons in the accelerating column rather than erosion by the arc. The angle and length of the ceramic expansion cup were chosen to match the plasma flux from the anode aperture to the extraction geometry. Various sizes of plasma aperture plates up to 10 mm inside diameter are used to change the operating range of the source. If lower currents are desired a smaller plate is used to permit source operation at high arc currents where the atomic mass fraction is better.

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* Atomic Energy of Canada Limited
Physics Division, Chalk River Nuclear Laboratories
Chalk River, Ontario, Canada K0J 1J0

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FINS Ion Source Performance

Figure 3 shows the total beam current as a function of arc and coil currents for a 10 mm source operating with hydrogen and with deuterium. The source was not optimized for deuterium because of personnel hazard involved in running deuterium beams on the unshielded Ion Source Test Stand. Atomic ion percentages for various currents are shown on the graphs. At all currents, heavy ions form less than 1% of the beam. Table 1 shows the measured normalized emittance for various total beam currents in hydrogen. The measurements include all the area in phase space to where the beam intensity is less than 1 part in 10^4 of the central current density. Thus the values given include the low density halo always present on duoplasmatron beams. The value for the old cup design shows the improvement on emittance with the new cup. The new cup design also decreases beam divergence.

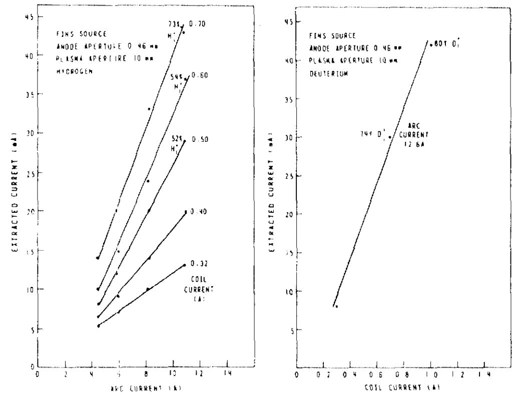

Fig. 3 FINS Ion Source Beam Current

Table 1

FINS Ion Source Normalized Emittance

	Emittance (π mm·mrad)	Fraction of Beam
FINS old cup design	2.30	1.00
44 mA, 74 kV	1.68	0.99
FINS new cup design	1.14	1.00
44 mA, 74 kV	1.02	0.985
FINS new cup design	1.00	1.00
17 mA, 74 kV	0.84	0.99

The source assembly is held in place by three clamps, one of which is shown in Fig. 1. When servicing is required the entire assembly can be rapidly removed and a new pre-assembled source can be installed. Source components that require replacement are the filament and the ceramic cup which is damaged mainly by backstreaming electrons. Erosion of the intermediate electrode canal is repaired by boring out the nose to approximately 7 mm diameter, plugging with an iron plug, and remachining the required nose shape. Similarly anode erosion can be repaired by machining out the central portion of the copper in the anode and brazing in a new plate and remachining. The anode can be replated about 10 times before it becomes distorted enough to require complete replacement. An attempt to use a molybdenum centre insert in the anode did not increase the time between replatings.

High Current Ion Source

The proposed design for an accelerator breeder[4] calls for a 300 mA 1 GeV cw beam from the accelerator. Experience at various laboratories suggests that initial beam processing at a 50-100 kV level would be advantageous. Thus as a preliminary stage, development of an ion source to provide a high quality 500 mA dc 50 keV proton beam is underway. The 500 mA value was chosen to allow for losses in bunching and in any emittance filtering that may be necessary. The primary requirement on the beam quality is low emittance (or high brightness), to reduce beam spill and resultant structure activation in the high energy end of the accelerator. This can only be achieved with a source that produces a uniform quiescent high-density plasma from which to extract a beam. For this reason the duoplasmatron source was rejected. Work presently underway at Oak Ridge indicates that the duoPIGatron source with modifications appropriate to lower current dc operation would provide a good starting point. Further requirements are high atomic fraction, good gas efficiency and stable spark-free operation. The latter is very important to reduce beam spill during faults and to reduce downtime. Another requirement set by the target is that the source must provide a current variable from some low value (say less than 10% of the design current) up to full current.

Figure 4 shows the present version of the source and extraction column. Because the high voltage power supply on the Ion Source Test Stand can only provide 500 mA this system is designed for 455 mA total beam.

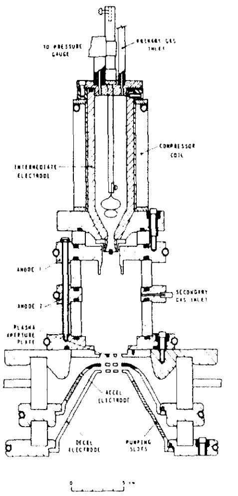

Fig. 4 High Current Ion Source

As with the Oak Ridge source, a molybdenum button and iron field shaping ring are used in the intermediate electrode. A gas inlet to the lower chamber of the source was found necessary to permit a wide stable operating range. A study underway to determine the optimum geometry for the intermediate electrode and anode region indicates that the design of this region is very critical for stable dc operation over a wide current range. There is a strong correlation between intermediate electrode aperture diameter and the spacing between anode and intermediate electrode. The extraction column uses 3 multi-aperture electrodes in an accel-decel configuration. The seven 4.5 mm diameter apertures are in a hexagonal array with shaped apertures used in the plasma aperture plate and cylindrical apertures in the accel and decel electrodes. A modified version of the Oak Ridge beam simulation code AXCEL[5] was used to calculate the required aperture shapes and spacings for 65 mA per aperture (0.4 A/cm^2) at 52.5 kV accel and 2.5 kV decel potential.

Figure 5 shows the beam current from the 7-aperture source as a function of arc and coil current.

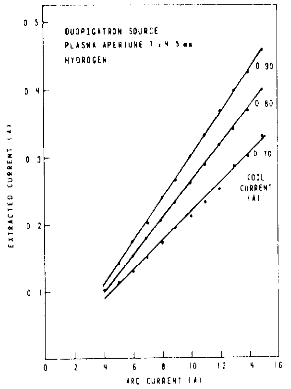

Fig. 5 High Current Ion Source Beam Current

Table 2 gives the measured normalized emittance and brightness for a single aperture and for three apertures in the measurement plane of the emittance measuring unit. Power density limitations on the emittance measuring unit do not permit emittance measurements at full beam current. However because the apertures are in a hexagonal array the emittance for the beam from the 7 apertures will be the same as the emittance for the beam from 3 apertures. However the brightness will be increased because of the higher current density in the central portion of the beam. Measurements of proton percentage have not been carried out at full beam current, again because of the limitations mentioned above. However measurements on a single aperture show the proton percentage is about 70% at full current. The gas consumption is about 40 Pa·ℓ/s (0.3 Torr·ℓ/s). Spark-free runs of more than two hours at 450 mA and more than 4 hours at 325 mA have been achieved. Development of this source is continuing.

Table 2

High Current Source Normalized Emittance and Brightness

	Emittance (π mm·mrad)	Brightness A/(cm^2·rad^2)	Fraction of Beam
Single Aperture	1.3	0.76 x 10^6	1.00
45 kV, 65 mA	0.33	0.12 x 10^8	0.92
Single Aperture	0.25	0.10 x 10^7	1.00
36 kV, 40 mA	0.9	0.13 x 10^8	0.95
3 Apertures	9.8	0.39 x 10^5	1.00
45 kV, 188 mA	8.6	0.52 x 10^5	0.95
3 Apertures	9.6	0.29 x 10^5	1.00
42 kV, 132 mA	8.1	0.41 x 10^5	0.96
3 Apertures*	8.8	0.47 x 10^5	1.00
40 kV, 183 mA	6.9	0.78 x 10^5	0.95

* Using 7-aperture plate with 4 holes masked.

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