A SMALL "COLD-CATHODE" HIGH-INTENSITY CYCLOTRON ION SOURCE

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Summary

High beam currents have been achieved with a radial source which fits into the 2-inch gap of a 30-inch cyclotron. The geometry is that of a cold-cathode or P.I.G. source. However, the cathodes are heated to thermionic temperatures by ion bombardment rather than a conventional high-current heated filament. The source is now in use and produces intense beams of H^+, D^+, He^3, and alpha particles. Internal beams of H^+ or D^+ of more than one mA are obtained routinely at extraction radius. In addition, 30 μA of H^- or D^- are obtained at a stripping foil by merely reversing the magnetic field of the cyclotron.

Introduction

The close spacing in the central region of our 30-inch cyclotron has led to the development of a small and comparatively simple ion source. An axial ion source of a more conventional design was considered, but the complicated positioning mechanism and compensation to avoid the magnetic field depression caused by a hole in the pole tips made the radial source preferable.

Most cyclotron ion sources are variations of a source described by Livingston.[1] This source consists of essentially a Penning[2] type discharge where the electrons are supplied by an electrically heated filament and are reflected back through the discharge region by an insulated reflector electrode. The elimination of the heated filament in the source was desirable because of the difficult problem of mounting and cooling in our restricted space.

A smaller version of the cold-cathode P.I.G.-type source described by Anderson and Ehlers[3] was first tried. This source would conduct only 20 to 30 mA with 2000 to 2500 volts applied at reasonable gas flow rates. This did not produce enough ions. On the test bench, where the gas flow could be increased to rather high levels, this source was run up to thermionic temperatures, and large outputs were obtained just before the cathode supports melted. It seemed apparent from this that if the cathode supports could be cooled while the cathodes ran at high temperature, the desired characteristics could be obtained. The source described here is based on this principle.

Description

The source is supported by two tubes--one above and one below the beam line. These tubes are supported by one large tube just outside of the maximum beam radius. The source itself is shown in Fig. 1. It is symmetric about the center line, and both cathodes are connected externally. The cathode supports are cooled by squirt tubes, and the temperature of the cathodes is determined by the cross section of the cathode stems. The cathodes are made of tantalum and can be easily replaced by removing the lids. The anode, or chimney, is held between two hollow copper blocks which are water-cooled by external water lines. The anode is free to rotate and can be easily removed by springing the two tubes apart. The ion exit slit is presently 3/64 x 9/64 inch.

Operation

At low pressure, the source operates as an ordinary P.I.G. source; that is, electrons are furnished by secondary emission and the impedance is high. As the gas pressure is increased, the current increases, the cathodes heat up and begin to supply electrons by thermionic emission. This increases the current with further cathode heating until the current is limited by the external circuit. This characteristic can be seen in Fig. 2. Here, arc current and voltage are shown for several pressures as the arc supply is gradually increased from zero. These curves were obtained from a strip chart recorder, and the transition to full thermionic operation can be clearly seen. The transition will not occur below a critical pressure. The minimum pressure at which the transition occurs and the impedance of the source are determined by the heat conduction of the cathode stems. Lower heat conduction results in higher cathode temperature and a lower arc impedance and voltage for a given current. Thus, by adjusting the heat conduction and varying the pressure, the arc voltage can be controlled for a given arc current. In practice, the cathode stems are cut to obtain optimum arc voltage and current for He^3 ion production. These conditions produce more H^+ and D^+ beam than can normally be handled.

The beam currents obtained at extraction radius for various particles are shown in the table.

Cyclotron Beam Currents

Particle	Beam Current at Extraction Radius
H^+	> 1.0 mA
D^+	> 1.5 mA
He^{3++}	> 120 μA
He^{4++}	> 120 μA
H^-	30 μA
D^-	30 μA

The H^- and D^- beams were obtained by merely reversing the magnetic field. Beam currents above 1.5 mA of H^+ and D^+ were avoided because of beam probe limitations. It appeared, however, that several mA could have been obtained. These beam currents were obtained within a few weeks after final assembly. Most of the time since has been spent on studying beam dynamics and on extraction system development using protons. Very little time has been spent with He^3 ions or alphas, and it seems likely that the source production of each of these can be increased if desired. The present arc supply is limited to 0.4 A, and a larger supply capable of 4.0 A has yet to be tried. The He^3 and alpha beams of more than 120 μA were obtained with an additional supply capable of 3 to 4 A temporarily connected. Control of this supply was difficult and the system was run for only a few minutes and not optimized.

The source is very stable in operation and can be turned on and off with little or no adjustment. Cathode life is around 100 hours, depending on arc voltage and type of particle. This could be increased by making the cathode thicker, but there is a practical limit since the sputtered tantalum will eventually restrict the arc column or flake off and short out the source.

Acknowledgment

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References

1. R. S. Livingston and R. J. Jones, Rev. Sci. Instr. 25, 552 (1953).
2. F. M. Penning, Physica 4, 71 (1937).
3. C. E. Anderson and K. W. Ehlers, Rev. Sci. Instr. 27, 809 (1956).

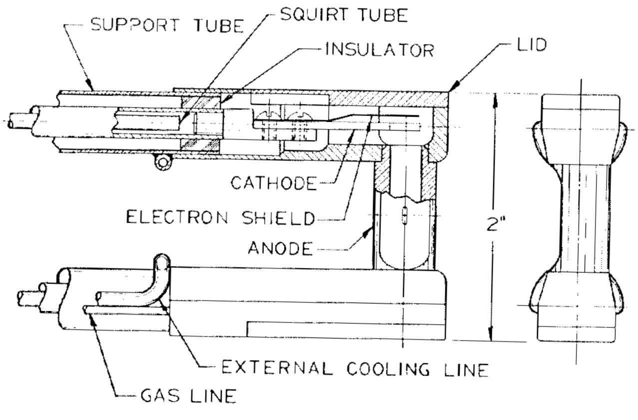

Fig. 1. Detail of ion source.

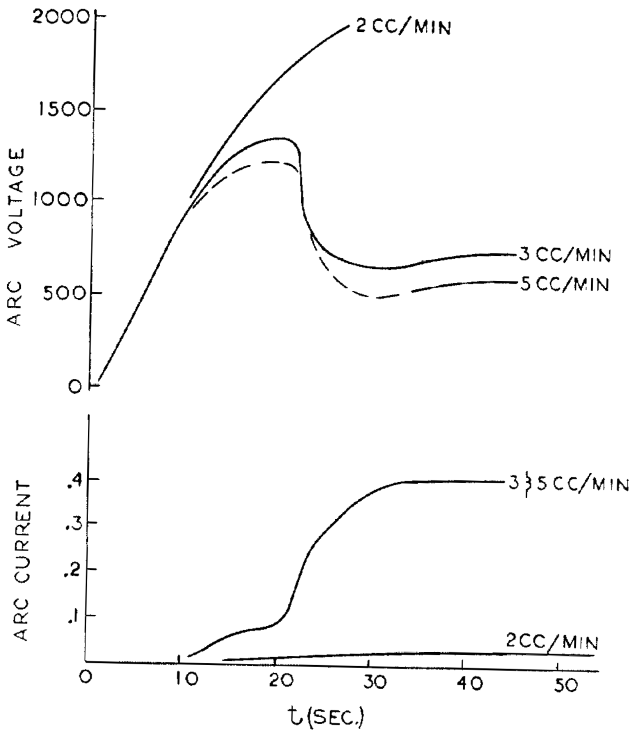

Fig. 2. Voltage and current characteristics showing transition to thermionic operation for 3 and 5 cm^3/min of hydrogen gas. The transition does not occur at 2 cm^3/min.