AN EXTERNAL HEAVY ION SOURCE FOR THE BERKELEY 88-INCH CYCLOTRON*

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Summary

A heavy ion source of the PIG type has been installed on the axial injection line at the 88-Inch Cyclotron. It is now in the testing phase. Arc powers up to 4 kW have been run, and hydrogen and nitrogen beams have been injected and accelerated in the cyclotron.

Introduction

Cyclotron ion sources are normally placed at the center of the cyclotron. The size of the source is limited in width by the first orbit radius to about 1-2 inches, and in height by the pole gap of 3-6 inches. Sources have been developed to fit this size, and are producing good intensity and high quality beams of both light and heavy ions. However, there are some beam requirements which are easier to meet with an external source. For polarized ions external sources are required and are in use on several cyclotrons, including the 88-inch.[1]

For heavy ions, internal sources are performing well at several cyclotrons. There are several advantages, however, in an external source. An external source can be larger, better cooled, and more easily maintained and developed. The increased gas stripping in the acceleration region due to pressure increase from the internal source gas can be avoided. Changing cathodes can be faster, and another source could be switched into the injection line during maintenance of one. If some of the development work on high charge-state ion sources is successful, they could be easily placed on the external injection line. For chemically reactive ions such as lithium, an external source would be easier to clean than the central accelerating area of the cyclotron. There is also the possibility of using tritium safely in an external source more easily than in an internal source.

For the 88-Inch Cyclotron the main use of the external heavy ion source is expected to be the production of lithium beams, and high energy nitrogen and oxygen beams for bio-medical studies and scattering experiments.

Design of the Source

For the production of highly charged heavy ions, the best source appears to be the Penning Ion Gauge or "PIG" type.[2] For the present source, the present version of the source originally developed for the Berkeley Hilac[3] was chosen as a starting point.

The PIG source and injection area are shown in Fig. 1. The source anode is biased to + 10 kV, so the beam is accelerated to 10 kV/charge by the puller at ground potential. The cathode is biased 1-3 kV negative with respect to the anode by the arc supply. The source magnet with a field of 2-5kG bends the beam through 120 degrees and selects the charge state to be transmitted. The exit edge of the magnet is cut back 25 degrees to give axial focusing to the beam. An iron shield, cut to the same angle, gives a sharp field cutoff and defines the magnetic edge.

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In Fig. 2 is seen a detailed view of the anode and puller. The anode is of water-cooled copper. The puller blades are replaceable tantalum sheets. The puller is remotely movable parallel to the anode face. The cathodes are tantalum cylinders mounted with set screws into water-cooled copper plates. Boron nitride insulators separate cathode and anode. They are mounted eccentrically to catch the tantalum cathode flakes falling from the ends of the horizontally oriented arc column.

In the following sections of the system, Fig. 1, the beam is transported through a 90 degree bend to the entrance to the quadrupole injection line.[1] Just beyond the source a plate with a cross pattern of holes is used with a motor-driven scanning wire to measure source emittance. An einzel lens and electrostatic mirror bring the beam to the injection line entrance.

The system is pumped by 2 six inch diffusion pumps. The injection line is presently pumped by a 4 inch diffusion pump and a sublimation pump, but about a factor of 2 greater pumping speed is needed to obtain the low 10^{-6} mm pressure desirable for transmitting heavy ions about 12 feet at 10 keV/charge.

The high voltage supply for the source is a commercial 20 kV, 150 mA unit. The arc supply was assembled at the lab from a surplus transformer-rectifier, controlled by a motor-driven variac mounted in a hot rack. The output is .5-3.5 kV at 5 amps. A series regulator tube can be used, but most of the initial tests have been with only a series resistor of about 400 ohms.

Initial Performance

The testing of the source began in late 1970. The first operation was with an uncooled inconel anode. It was found that the output of N^{+4} and N^{+5} beams was poor and that the anode melted near a cathode. Also a great quantity of flakes was produced. An improvement was obtained when water cooling was added along the side of the anode. A further improvement came by using water-cooled copper, instead of inconel. This gave both better arc stability of 3-4 kW, and better high charge state production. At present the arc runs stably up to 1 kV × 4A = 4 kW.

The charge distribution at optimum gas pressure of a nitrogen beam of 10 kV was measured on the Faraday cup after the source (Fig. 1). It is shown in Table 1.

	N^{+1}	N^{+2}	N^{+3}	N^{+4}	N^{+5}	V_{arc}	I_{arc}
% Beam	32	40	23	4.1	.36	1 kV	3.1A

Table 1. Nitrogen beam charge state distribution. Total beam current was about 10 milliamps.

An initial measurement of the emittance of the source with the cross-plate and scanning wires just beyond the source was made. The values are 900 mm-mr vertically, and 500 mm-mr horizontally, for about 80% of the beam in each plane. The vertical plane is the bending plane, so that emittance includes source energy spread.

Some initial transmission measurements into the cyclotron were also made. For protons the overall transmission from the source to the external cyclotron beam is about .5% without a buncher. By more careful matching of source emittance to the line, and by use of the buncher this should approach the 5% obtained with the polarized source. Beams of N^{+3} and N^{+4} were injected and accelerated in the cyclotron. These tests indicate that the overall transmission from source to external beam would be about .05%. The reduced transmission is due to gas charge exchange in the injection line and the cyclotron. By improving the injection line pressure, the optics, and using the buncher this transmission should approach 1%.

Some Operating Procedures

The source was more stable when a 100 K-ohm resistor was inserted in parallel with the anode and cathode, and a 10 M-ohm between cathode and ground. These resistances were necessary to suppress the bleeder effect of the parallel water cooling system, common to components of the PIG source.

Sooner or later some short-circuits appear due to flakes. Those taking place between puller and anode can be removed by moving the puller back and forth in parallel motion to the slit. Shorting in the cathode-anode space needs more brutal force. Shorting the series resistor enables a very high current to be applied to the short, vaporizing it. The only trouble we got with such a method was to damage the BN insulator sometimes. As presently installed, the source slit is pointing downwards. Some flakes could stay on the anode slit but they are burned by the plasma and fall down. Other flakes could stick to the puller slit and are intensely heated by the beam impinging on them. They are an intense electron source loading the accelerating supply by more than 50 mA. A tantalum dump is used to dissipate this extra power from the electrons drifting in the crossed E and H fields.

Two powerful modes of operation of the arc are possible. A positive resistance (+ R) mode (1A of arc at 2 kV) and a negative resistance (- R) mode (3A or more at 1 kV or less). In this last mode the cathodes are hot enough to emit thermionic electrons, the highest charge state are produced, and some "filaments" are seen between both lips of the anode slit. In the +R mode the beam is not seen when looking axially at it, while in the -R mode the beam is clearly visible, due to a high proportion of excited ions. A less powerful arc (0.1 to .3 A at 3 kV) exists when starting the arc. It was most used when running the PIG source as a proton source.

The rate of consumption of the Ta cathodes is about 0.75 to 1.2 G/hour. After 1 1/2 - 2 hours of 3 kW arc the flat top cathodes are deeply eroded; a crater about 5 mm deep is formed. To increase the lifetime of the cathode, more material is needed. A 45° cone cathode runs for 3 hours. A more pointed 60° angle version did not work, probably due to the steep slope. Our observation is that the cathode ends its life not by the depth of the crater, but by the slope. A cathode with one or more circular grooves could be conceived; the top side of the crater could fall down in pit of the insulator, already used to collect the flakes coming from the deposit on the conical inside part of the anode. Two tungsten cathodes were tried. They needed too high a pressure to run and we were unable to get a -R mode with them. This was due to the better thermal conductivity and higher emission temperature of tungsten. A combination of one tungsten and one tantalum cathode was tried. They gave about the same result as a two tantalum cathodes but the tungsten cathode is consumed 35% faster in volume than the tantalum one.

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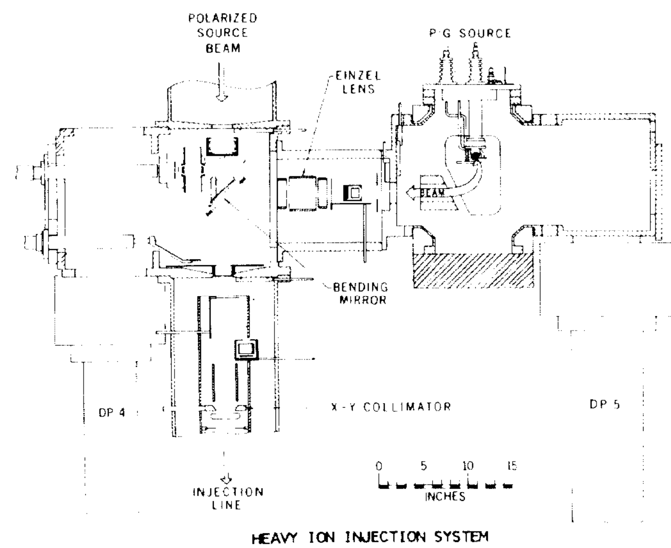

Fig. 1. PIG source injection system showing source, focusing lens, bending mirror, Faraday cups, and scanning wires for beam monitoring.

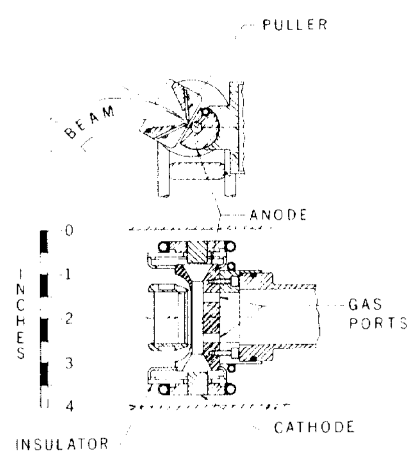

Fig. 2. Cross-sections of anode-puller region.