A Compact RF Driven H⁺ Ion Source for Linac Injection

J. Patrick Rymer, G. A. Engeman, R. W. Hamm and J. M. Potter
AccSys Technology, Inc.
1177 Quarry Lane
Pleasanton, CA 94566

Abstract

A compact rf driven H⁺ ion source has been developed for use as an injector for the AccSys radio frequency quadrupole (RFQ) linacs. A multicusp magnetic bucket geometry developed at Lawrence Berkeley Laboratory confines the plasma created by an antenna driven by 35 kW (peak) of pulsed rf power at 1.8 MHz. A three electrode system is used to extract and accelerate the H⁺ beam, which is then focused into the RFQ by an einzel lens. Permanent magnets in the extraction region sweep electrons onto the second electrode at energies up to half of the full acceleration voltage. A fast pulsed valve allows the hydrogen gas supply to be pulsed, thus minimizing the average gas flow rate into the system. The design features and performance data from the prototype are discussed.

I. INTRODUCTION

A compact H⁺ ion injector has been developed for the RFQ linac system that will be used as a calibration source for the L3 experiment at CERN. The injector consists of an rf driven ion source, extraction and focusing optics, and associated vacuum equipment. The 30 keV H⁺ beam from the injector is accelerated by an RFQ to 1.85 MeV, and then stripped to H⁰ in a gas neutralizer, so that it can drift through the magnetic field of the L3 magnet to a lithium target inside the electromagnetic calorimeter. The radiative capture gammas from the Li(p,γ) reaction are used to calibrate the BGO detectors in the calorimeter. This application of an RFQ has been previously described[1].

The injector parameters required for operation with the standard AccSys PL-2 RFQ used in the L3 system are listed in Table I.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection energy</td>
<td>30 keV</td>
</tr>
<tr>
<td>H⁺ current (peak)</td>
<td>20 mA</td>
</tr>
<tr>
<td>Maximum e⁻/H⁺</td>
<td>50</td>
</tr>
<tr>
<td>Minimum pulse width</td>
<td>50 μsec</td>
</tr>
<tr>
<td>Max. pulse repetition rate</td>
<td>150 Hz</td>
</tr>
<tr>
<td>Emittance</td>
<td>&lt;0.5 πmm-mrad</td>
</tr>
</tbody>
</table>

The rf driven volume ion source used in the AccSys H⁺ injector is based on the one developed by Leung, et. al. at Lawrence Berkeley Laboratory (LBL) under subcontract to AccSys[2]. A multicusp magnetic field geometry using samarium cobalt magnets provides plasma confinement inside the 10 cm diameter bucket. Hydrogen plasma is produced by driving a helical antenna with up to 35 kW of peak rf power at a frequency of about 1.8 MHz. The water cooled antenna is made of copper tubing which is coated by a thin glass layer applied using the technique developed at LBL. The glass insulates the antenna from the plasma and protects the copper tubing from plasma bombardment. A small heated tungsten filament provides electrons to allow plasma ignition at lower pressures than possible with only the rf drive. The source geometry and its mounting arrangement in the injector are shown in Figure 1.

Figure 1. Cross-sectional view of AccSys H⁺ injector.

The ion source is divided into two plasma regions by water cooled tubes containing NdFe permanent magnets which produce a maximum dipole field of about 120 G. A
stainless steel insert containing the extraction aperture is mounted on the plasma electrode along with a stainless steel collar which projects back into the source to reduce the extracted electron current[3]. Hydrogen gas is injected by a modified automotive fuel injector valve that is pulsed at the same repetition frequency as the plasma[4]. The pulse width applied is variable, as is the delay between the valve pulse and the plasma pulse. Average source pressure is monitored by a thermocouple gauge.

The antenna is driven by a pulsed amplifier which uses a 3CPX1500A7 tube driven in Class D operation by power MOSFETs. Isolation from the ion source high voltage is provided by a balanced rf transformer. The antenna is resonated by two external inductors and a capacitor located at the back of the source. Impedance matching is provided by connecting the isolation transformer output to various tap points on the inductors. A simplified schematic of the rf and high voltage circuits is shown in Figure 2.

The high voltage circuit used to implement these voltages is shown in Figure 2. The plasma electrode is isolated from the source so that it can be biased up to +10 V with respect to the source body. Injection energy and extraction voltage are independently adjustable. A potential difference of 15 kV is nominally applied between the plasma electrode and the extractor electrode. Two permanent magnets in the extractor electrode create a dipole field which bends extracted electrons into a cavity in this electrode, while deflecting the ions only slightly. The ions are then accelerated across another 15 kV gap between the extractor and the ground electrode. A second magnetic dipole in the ground electrode corrects the first angular deflection of the ion beam. A current transformer mounted in the ground electrode measures currents leaving the accelerating column.

The accelerating electrode geometry is made as open as possible for vacuum pumping, to minimize H⁻ stripping. The injector chamber ion gauge pressure is typically 1 to 2 x 10⁻⁶ Torr during operation, while the source chamber pressure is typically 15 to 20 mT. Differential pumping of the RFQ vacuum chamber is provided by the restricted openings of the ground electrode and einzel lens mounted on the flange separating the ion injector and RFQ.

V. DATA

Extracted H⁻ and electron current from the rf driven ion source were first measured by temporarily replacing the ground electrode with a simple spectrometer as shown schematically in Figure 3. Two permanent magnets were mounted in the extraction electrode to bend the extracted electrons into a recess in the spectrometer body. The slightly deflected H⁻ ions were collected on an isolated electrode at ground potential and measured through a resistor to ground. A guard ring biased at -300 V was used to suppress secondary electrons from the ion collector. Total power supply current was monitored to determine the extracted electron current.

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Figure 2. Schematic of the H⁻ ion injector circuits.

III. DESCRIPTION OF THE INJECTOR

As shown in Figure 1, the ion source is mounted into a re-entrant vacuum chamber, with the extraction and focusing optics mounted on the opposite flange. A vacuum valve and cryopump are mounted on a flange which is attached to a rectangular opening in the chamber. A high voltage enclosure is also mounted on the vacuum chamber to provide high voltage protection of the ion source and its connections. Hence, there is no exposed high voltage during operation of the injector. In addition, the ion source and beam electrodes are mounted precisely with respect to two pins which align the injector beam axis to the axis of the RFQ when the ion source vacuum chamber is attached to it.

IV. EXTRACTION AND FOCUSING OPTICS

A three electrode system is used to extract the ion beam and accelerate it to 30 keV. This acceleration column is followed by an einzel lens to focus the beam into the RFQ.

Figure 3. Schematic of spectrometer setup for H⁻ measurements.
Figure 4 shows the H⁻ current and the ratio of electron current to H⁻ current measured by the spectrometer as the gas pressure in the ion source chamber was varied using a plasma aperture of 0.48 cm diameter. Both quantities change slowly with pressure. Figure 5 shows the same two quantities measured as a function of antenna rf power. The H⁻ current was still increasing at the maximum rf power available from the amplifier, but the current achieved was sufficient for use with the L3 calibration system.

Figure 4. H⁻ current and electron to H⁻ ratio as a function of gas pressure.

Figure 5. H⁻ current and electron to H⁻ ratio as a function of ion source rf power.

The ion injector has been assembled with all the electrodes present and H⁻ ions have been accelerated to 1.85 MeV in the RFQ. An output current of 5 mA was obtained from the RFQ in the initial tests with an input current of 8 mA through the injector einzel lens. The accelerated beam that was transported to the gas stripper is shown in Figure 6. Further tests are in progress to improve the beam transmission through the ion injector beam optics and to match the beam into the RFQ linac.

Figure 6. 1.85 MeV H⁻ beam from Model PL-2 RFQ using the rf driven H⁻ ion source operating at 60 Hz. The vertical scale is 0.5 mA/div and the horizontal scale is 5 μsec/div.

VI. CONCLUSION

The compact rf driven H⁻ ion injector developed by AccSys has been shown to be a very stable, easy to operate system. This injector, which is operated from the AccSys computer control system[5], should have a long lifetime and produce a high current beam for injection into an RFQ linac. Installation of this first system will occur later this year at CERN.

REFERENCES