Low-Energy H⁻ Injector Design for SSC RFQ*

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Abstract

We present a design for the low-energy H^- injector. It is used in conjunction with a rf-driven multicusp source and will deliver 30 mA of H^- at 35 kV, at a pulse length of less than 1 msec to a RFQ downstream (used in the LINAC booster of the SSC, for example). It has several distinguishing features and meets the goal of having an outgoing beam free of electron contamination, with small radius, large convergent angle and small projectional emittance.

The specific example presented meets all the requirements of the injector for SSC RFQ. However, the principle and method used should easily be adapted for the designs of injectors with similar requirements for other purposes.

I. INTRODUCTION

Advances [1] have been made with the recent works on the rf-driven, cesium free volume production multicusp H^- source which operates at relatively low gas pressure (p ~ 10 mT), and yields high ion current density (j_i ~ 100 mA/cm^2) with low extracted electron to ion ratio (j_e/j_i ~ 10) and low ion temperature (kT_i ~ 1.5 eV). In this paper we describe a design of an injector that would couple with such a source and would deliver a useful H^- beam to a RFQ, for example, with desirable matching parameters. In the specific example provided, the exiting H^- beam of 30 mA at 35 kV has to meet the following requirements in order to match the Twiss parameters for the RFQ: beam radius = 0.2 cm, convergent angle = 139 mrad, and ε =0.018 π-cm-mrad. The injector consists of four electrodes and is operated in an accel-decel-accel scheme similar to the other injector design [2]. The first two electrodes employ an acceleration voltage of 50 kV to extract the negative ions and the unwanted electrons. The latter are swept away by a pair of permanent magnets embedded in the first electrode. (The reason to choose the 50 kV value is to provide enough gap spacing for those deflected electrons to reach the second electrode.) The H^- beam is then decelerated by the third electrode (normally biased at the same voltage as the first one). The beam expands as it slows down. It is then reaccelerated and compressed by the fourth electrode, which is also the entrance to the RFQ. Several technical improvements have been made over the preliminary version reported earlier [3]. They are described in Sec. II-IV below. Further improvements and extensions of the design are discussed in Sec.V.

II. SPECIAL TECHNIQUES USED IN THE DESIGN COMPUTATION

We use an axisymmetric 2-D ion beam optics code to compute the charged particle trajectories. In order to be precise, we include the effect of the attenuation of the H^- beam due to gas stripping by modifying the current density along the z axis with the function f_i shown in Fig.1. This survival function of j_i is a fit to the numerical result based on the stripping cross-section of H^- by neutral molecules, the pressure profile of which comes from a molecular flow calculation performed previously[3]. For the extracted electrons, a method has to be devised to simulate their space charge effect, at least in the direction of the symmetry axis. We use the function f_e shown in Fig.1. It accounts for the full effect near the source aperture and is gradually turned-off about 1 cm away.

In order to compute the rms projectional emittance, it is necessary to use the "skew beam dynamics" described in Ref.[4]. It also gives more accurate numerically convergent results.

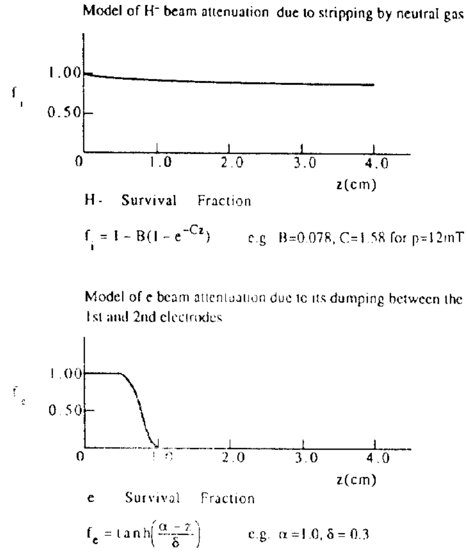

Fig. 1 Models of Beam Attenuations

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III. DESIGN GOALS AND THE RESULTS

The specific goal mentioned in Sec.I is fulfilled with the design shown in Fig.2.

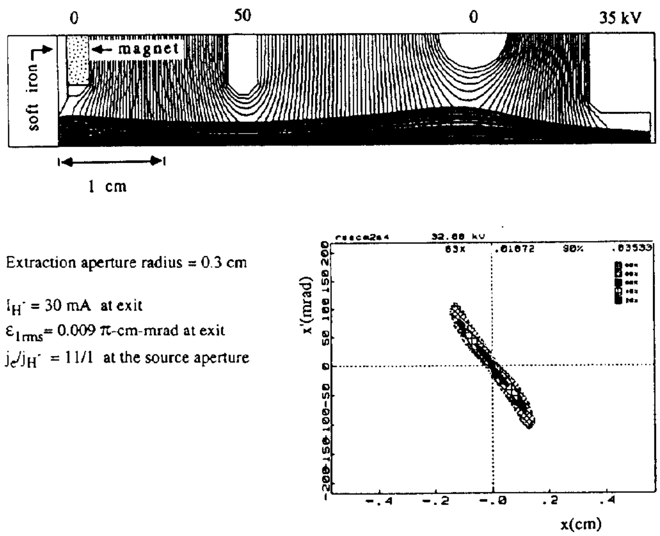

Fig. 2 Axisymmetric Beam Trajectory Plot and Exit Phase

An H^- current density j_i = 115 mA/cm^2 is assumed at the source aperture which has a radius r = 0.3 cm. As the beam travels about 6 cm to the exit, it retains about 92% of its current according to the function f_i shown in Fig.1. We also assume a uniform current density distribution at the aperture and an ion temperature of 1.5 eV. Thus the initial rms emittance is 0.006 π-cm-mrad at that location. The x-x' phase plot in Fig.2 shows 90% of the emittance as the beam enters the last electrode. The length of the first gap is chosen in such a way that it nearly saturates the Child-Langmuir limit, once the acceleration voltage of 50 kV is chosen. The shape of the first electrode is optimized to ensure a flat plasma emitter, which is defined by the once-integrated Poisson equation, and there is a relatively low electric field (E~1000 kV/cm) across this emitter. (The voltages of the four electrodes are 0, 50, 0, and 35 kV. Alternatively, they can be labelled as -35,15, -35 and 0 kV).

The potential of the third electrode is normally equal to that of the first one. However, if a larger convergent angle of the beam into the RFQ is desired, it should be biased at a few kV negative. Thus one can adjust the beam angle continuously to provide the proper entrance angle for a particular RFQ requirement. An example is shown in Fig.3.

IV. DUMPING OF THE ELECTRONS

One of the problems of extracting negative ions from a volume source is that the beam contains a large amount of unwanted electrons. Putting a pair of permanent magnets (e.g. SmCo) inside the first electrode can sweep those electrons out of the beam at the early stage of acceleration. However, a closer examination of this solution[3] reveals

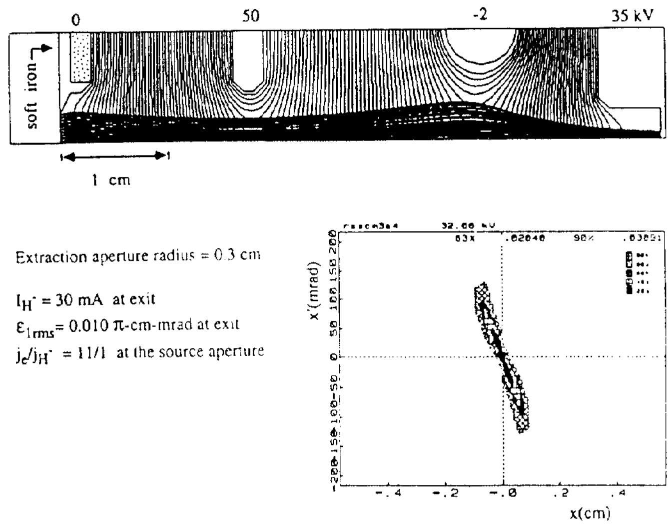

Fig. 3 Axisymmetric Beam Trajectory Plot and Exit Phase with a Larger Convergent Angle

that the magnets of proper size and strength to achieve this result would also produce a B field of about 500 gauss at the source aperture, extending and gradually diminishing into the source chamber. Fig.4 shows the calculated and measured B field as a function of axial position. This penetration would have a destructive effect on the H^- production there.

A method is found to solve this problem. We replace the usual material copper for making the first electrode with soft iron, with the location of the magnets shown in Fig.2 and 3. This soft iron housing has the effect of shifting the peak of the B field away from the source and greatly reduces the penetration, as shown in Fig.5.

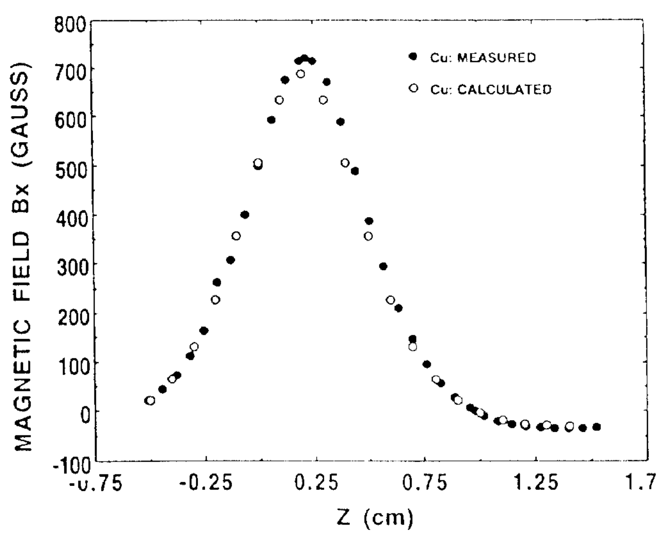

Fig. 4 Comparison of the Axial B Fields: Calculated and Measured, both with Copper Housing

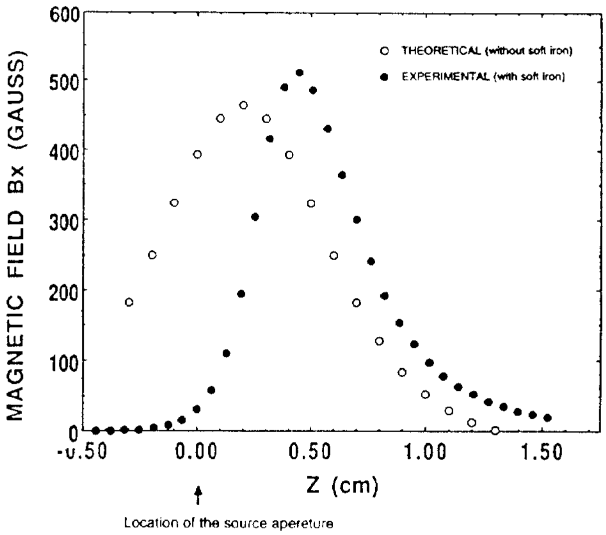

Fig. 5 Comparison of the Axial B Fields: Calculated (with Copper Housing) and Measured (with Soft Iron Housing)

In Fig.6 we simulate this shifted B field in a planar calculation to study the trajectories of the electrons. The exact landing location of the electrons on the second electrode is not critical as long as they are stopped from going further downstream. Since the present design is for short pulse operation (less than 1 msec.) and low duty factor, the heat loading should not pose a problem, especially if active cooling is employed.

There is one further advantage of the accel-decel design. There exists an electric field reversal before and after the second electrode. Any secondary emission of electrons produced by the impact of the extracted source electrons on the upstream face of the second electrode would be confined to the first gap and would not migrate downstream to cause head-loading damage or to produce x-rays.

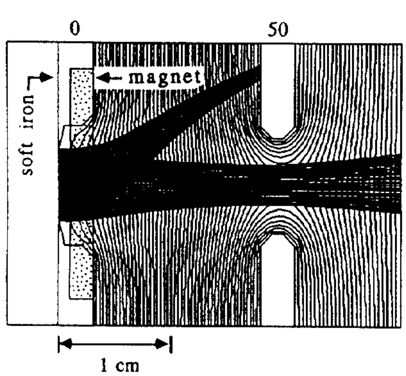

Fig. 6 Planar Calculation Showing the Effect on the Extracted Electrons due to a Pair of Magnets Located Inside the 1st Electrodes

V. DISCUSSIONS AND CONCLUSIONS

We have shown in Sec.III and IV a design of a compact injector to produce an H^- beam with large convergent angle and low emittance. The overall arrangement, including the source, is shown in Fig.7. The exit emittance is about a factor of two smaller than the SSC RFQ injector requirement. This is achieved by good ion beam optics and the low H^- ion temperature. In this study we have ignored the contribution of the emittance growth due to the perturbation of the ion trajectories by the magnetic field, as well as its steering effect on the beam as a whole. However, we don't expect these effects to be dominant factors. We intend to investigate them in 3-D calculations in the future.

The question of how to dump the electrons without interference with the source performance and ion beam optics is a long standing problem for H^- extraction. We believe we have found a simple method, described in Sec.IV, to decouple those issues. The modification of the present design to accommodate dc operation is under study and shall be reported elsewhere.

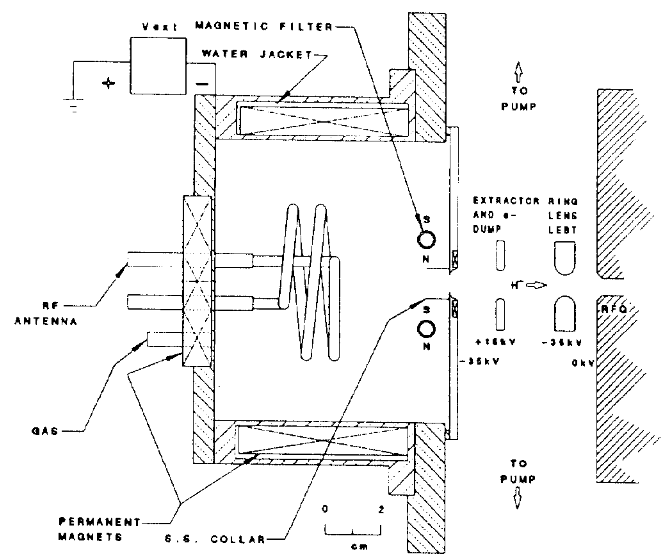

Fig. 7 Schematic Diagram of the RF Multicusp Ion Source

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