DESIGN OF A 200 mA DC H^- INJECTOR FOR AN RFQ

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We discuss the design of a high-current DC H^- injector system. A few of the system features are: (1) a carefully designed electron trap in the accelerator which does not produce appreciable aberrations in the H^- beam, (2) open accelerating and transport structures which allow a high rate of gas pressure reduction, and (3) exclusive use of electrostatic focusing in the transport section which prevents plasma buildup and eliminates possible emittance growth from plasma fluctuations.

Introduction

In this paper we discuss the design of an H^- injector for an RFQ. The injector system consists of a volume-production ion source [1], a 100 keV electrostatic accelerator with a built-in electron trap, and an electrostatic transport and matching system. The injector is intended to accelerate 200 mA of H^- and is designed for DC operation. The DC requirement makes the design quite different from a short-pulse system because of the need for water cooling of all components and because of the need for extensive gas pumping.

Major emphasis is placed on minimizing beam emittance and this dictates several design criteria. First, we have chosen a volume-production H^- source, a type of source capable of producing DC beams with low emittance. The source operates at a pressure of more than 10 mTorr, which requires that careful attention be paid to pumping away the residual H_2 gas to avoid excessive loss by stripping of the H^- beam. This goal is achieved by designing an open accelerator and transport structure, with high conductance to pumps.

Electrons in the beam must be removed before they have been accelerated to the full energy of our accelerator; otherwise, the power loading on electrodes would be severe, and breakdown problems would be aggravated. The first group of electrodes of the accelerator forms an annular Faraday cup, which captures these electrons as they are deflected by built-in permanent magnets. This structure has been carefully designed to minimize the introduction of aberrations in the H^- beam.

We use an electrostatic system to transport the beam from the 100 keV accelerator to the entrance of the RFQ. This system performs several functions: It provides sufficient length for effective pumping. It prevents the accumulation of charge and the formation of plasma in the transport channel, thus eliminating emittance growth caused by plasma instabilities. The final elements of the transport system form an electrostatic focusing lens to match the beam to the RFQ. Our design is intended to perform these functions with minimum emittance growth.

We discuss two conceptual designs for the transport channel: one version based on electrostatic quadrupole (ESQ) focusing, and another using a series of axisymmetric aperture lenses. The first version is essentially a pencil-beam version of the sheet-beam transverse-field focusing (TFF) system which was previously tested at LBL [3], and many of its characteristics are similar.

The components and features of our RFQ injector designs are discussed in the following sections.

Electrostatic H^- Accelerator and Electron Trap

The general layout of the ESQ version of our system is shown in Fig. 1. In order to improve the beam emittance, we use a volume-production H^- source [1] instead of the surface-production type [2] used in our TFF system [3]. Because of this change in type of source, the ratio of electron to H^- current is expected to be at least several times larger than in Ref. [3]. This means an excessive electron power load unless the electron trap is placed in a low-voltage location. We use magnets to sweep primary electrons from the beam at low voltage and follow the JAERI scheme [4] which includes an electrostatic trap to confine secondary electrons. However, we have made several modifications in order to reduce H^- beam aberrations. Our design is shown in Fig. 2.

The problem in designing a high-current accelerator with a low-energy electron trap is that space charge tends to cause the ion beam to expand in the low-energy section. If the beam approaches the electron trap structure, large aberrations can result. To avoid such problems, we carefully optimized the shapes and sizes of all electrodes. Particular attention was paid to the shape of the third element of the three-piece trap structure. Our optimization took into account the problems of electrical stress, beam aberrations, trapping of secondary electrons, and sensitivity to changes in power supply voltage.

Simulation of the optimized design gave an rms beam angle of 0.35 degrees; see Fig. 3. Although this is several times lower than the value given by the JAERI design, it is still somewhat higher than the theoretical value based on ion temperature.

Figure 3 also shows equipotential surfaces in the annular Faraday cup (electron trap); there is a potential well which confines secondary electrons. Fig. 4 shows the orbits of the primaries; from these, the primary electron heat load was estimated and used to design suitable water-cooling passages in the electron dump. In addition to the semi-3D code used for Fig. 4 we employed another (2-D) code which accurately models the finite-length magnets in the electron trap. When the magnet length was optimized, it turned out to be only somewhat larger than the diameter of the electron dump.

We have used our 2-D code to estimate the magnetic steering of the H^- beam field and to estimate the electrode displacement needed to reduce the final beam angle to zero. Suitable lateral adjustment of the accelerator electrode has been provided in the design.

The engineering design of the 200 mA DC accelerator and electron trap has been completed. Construction is scheduled for completion this summer. Meanwhile, testing and development of the volume-production source is underway using a short-pulse prototype accelerator of smaller diameter [5].

Electrostatic Quadrupole Transport

We are presently developing conceptual designs for electrostatic beam transport, as discussed in the Introduction. One of the designs is seen in the right-hand part of Fig. 1. This is a new approach for intense H^- beams, in that it uses ESQ transport instead of the usual combination of magnetic quadrupoles and gas neutralization. Our aim is to avoid the plasma-fluctuation problems that the latter can create. This design was carried out with the help of an envelope code borrowed from the LBL Heavy-Ion Fusion Accelerator Research (HIFAR) group [6]; we also took advantage of their experience with electrostatic transport of intense Cs^+ beams. We adapted one of their designs [7] which matches a round beam to a

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periodic ESQ structure. In order to produce a round beam at the transport exit, we simply followed the matching part of their structure with an inversion of itself. The result has the symmetry seen in Fig. 5.

Note that the beam envelope in this particular design has large excursions and comes fairly close to some of the electrodes; the possibility of sizeable aberrations still needs to be investigated.

Axisymmetric Aperture-Lens Transport

The advantage of ESQ transport is that there has been considerable LBL experience with it in the HIFAR group, as mentioned above. One disadvantage is the difficulty of making exact simulations; in particular, it is not easy to compute beam aberrations. Therefore, we have also considered an alternative concept (Figs. 6 and 7); because of its axisymmetry it can be easily simulated, and also it can be quite compact. (Note that this is not an einzel lens scheme; einzel lenses have field-free drift regions which we wish to avoid since plasma can accumulate in such regions.)

The simulation (Fig. 6) shows that the beam deflections are small and the aberrations are completely negligible. Figure 7 shows a conceptual transport system based on the aperture-lens approach. In this design, larger insulators and clearances have been used to improve the pumping conductance as discussed below.

Matching to RFQ

One of the great difficulties in designing an RFQ injector is in the beam matching: a very small beam diameter and very large convergence angle are required just inside the RFQ entrance. As an illustration of this problem, we modified the arrangement of Fig. 5 to provide such matching and found that completely unrealistic electrode voltages were required. Therefore we are investigating instead an aperture-lens matching arrangement to be used with either of the transport concepts just described. A simulation of such a matching scheme is shown in Fig. 8. Although this design has not yet been optimized, the aberration obtained is not much larger than that introduced by the accelerator/electron trap module.

Pumping Calculations and Beam Loss

We used a Monte Carlo code to study the effect of the large gas efflux from the ion source. We modeled the gas pressure profile for the injector system and used this profile to calculate the H^- stripping loss. We found that substantial loss would occur in the accelerator if the only pumping were along the grid axis (curve A in Fig. 9). For the best case (addition of perfect pumping radially between grids 2 and 3) we found acceptable stripping loss (curve B). We expect even better results with the layout of Fig. 7, which has better conductance throughout.

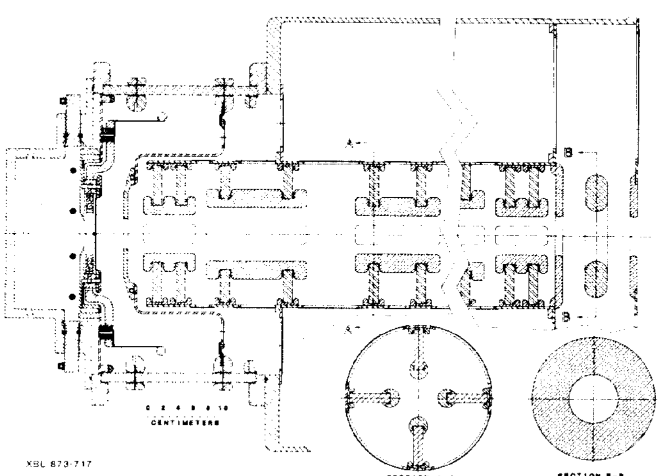

Fig. 1. Layout of ESQ version of injector. Less than half of the transport section is shown.

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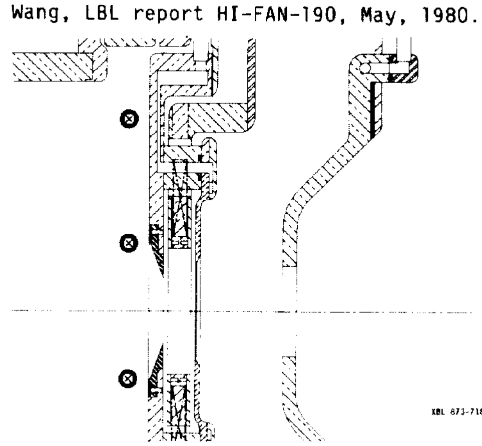

Fig. 2. Detail from Fig. 1 showing the 100 kV accelerator. The first group of electrodes forms an annular Faraday cup and contains the magnets which deflect electrons into the cup.

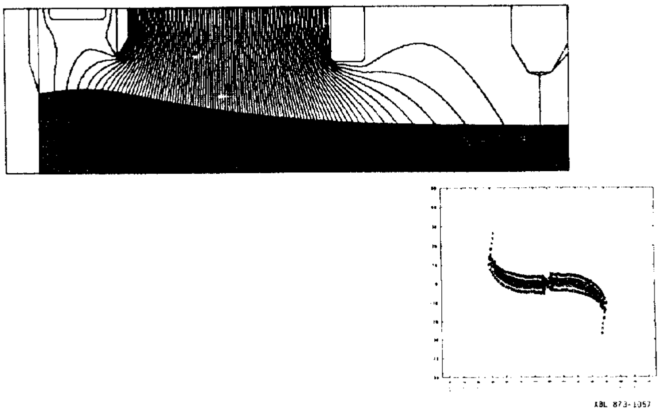

Fig. 3. Simulation of ion optics in the 100 kV accelerator, showing beamlet trajectories and exit phase plot.

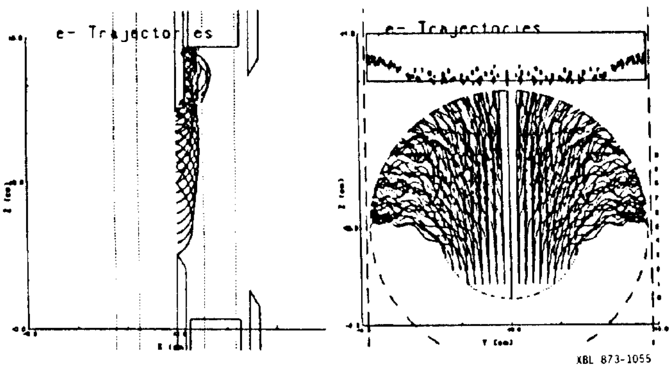

Fig. 4. Simulation of electron trajectories for the electron trap: side view, and downstream view.

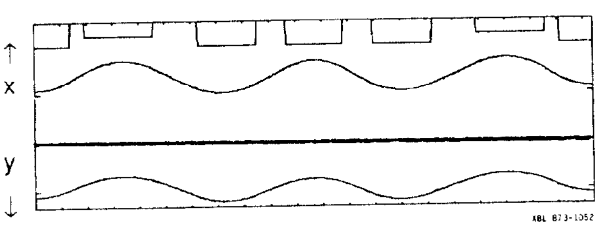

Fig. 5. Simulation of beam envelope along the ESQ transport section of Fig. 1.

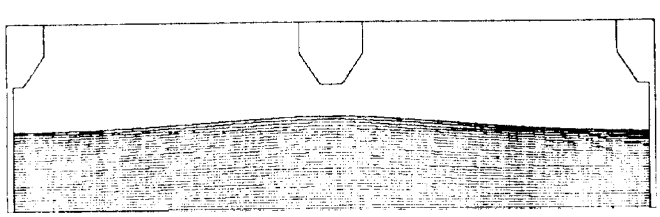

Fig. 6. Simulation of beamlet trajectories in a section of the alternative transport system using aperture lenses. The envelope excursions are much smaller than in Fig. 5.

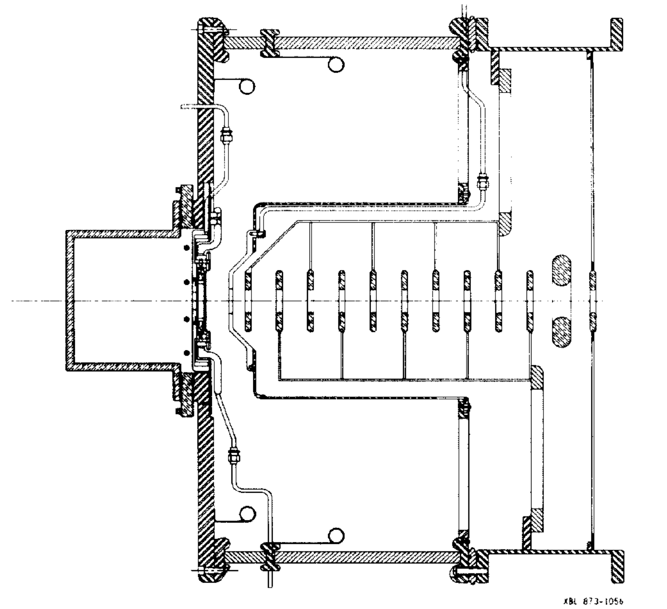

Fig. 7. Layout of injector system using the aperture-lens modules simulated in Fig. 6. The accelerator here has a larger insulator than in Fig. 1 for improved gas pumping.

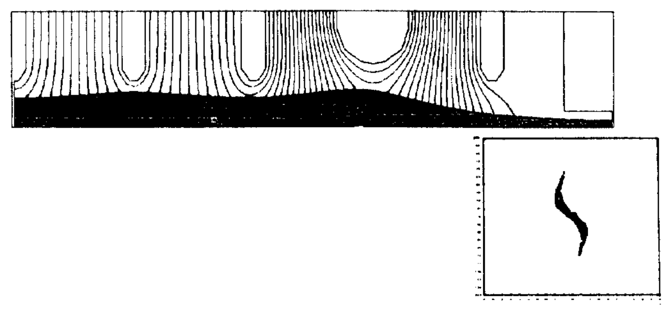

Fig. 8. Simulation of an axisymmetric matching lens for RFQ, showing beamlet trajectories and exit phase plot.

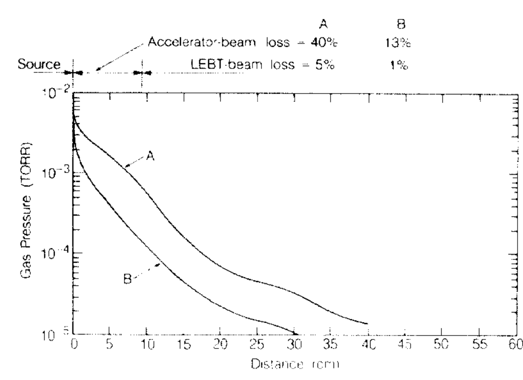

Fig. 9. Monte Carlo simulations of gas pressure in the injector system of Fig. 1. Curve A: Pumping through center only. Curve B: Additional perfect pumping between electron trap and accelerator grid.