2-MV INJECTOR FOR HCX*

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Abstract

We report on development of the Heavy-Ion Injector at LBNL, which is being prepared for use as an injector for the High Current Experiment (HCX). It is composed of a 10-cm-diameter surface ionization source, an extraction diode, and an electrostatic quadrupole (ESQ) accelerator, with a maximum current of 0.8 A of potassium ions at 2 MeV, and a beam pulse length of 3 μs. We have improved the Injector equipment and diagnostics, and have characterized the source emission and radial beam profiles at the diode and ESQ regions. We find improved agreement with EGUN predictions, and improved compatibility with the downstream matching section.

1 INTRODUCTION

A typical heavy-ion fusion driver has 84 beam channels with each channel transporting a beam of line charge density 0.25 μC/m. An ESQ injector [1,2], representing a single driver beam, has been in operation at Lawrence Berkeley National Laboratory for several years. Figure 1 shows a cross sectional view of the Injector. Previous performance of the Injector produced a beam with adequate current and emittance for the Elise project but with a hollow intensity profile at the end of the ESQ section [1]. Recent work on the Injector has had the goals of studying the behavior of the beam in the source and diode regions, improving the reliability of the equipment, and preparing the Injector and matching section for the role of injector for the HCX. HCX [3] has the goal of studying the transport of high current and high charge density beams produced by the Injector through several plasma periods in electrostatic and magnetic quadrupole transport channels.

2 EQUIPMENT AND DIAGNOSTICS

The Injector is contained inside a pressure vessel that houses the Marx generator, the high voltage dome containing the ion source and electronics, and the ESQ transport and accelerating section. The pressure vessel provides electrical insulation of the high voltage structure and is typically pressurized at 5.3 atmospheres of a dilute mixture of SF_6 in N_2. At present the source is a 10-cm diameter spherically curved, hot porous-tungsten contact

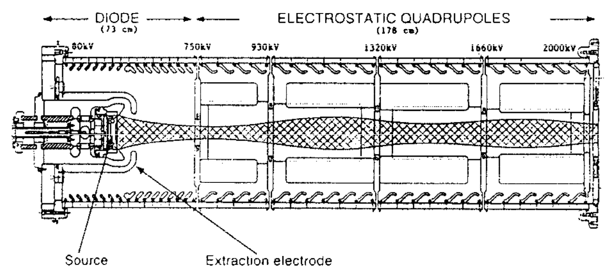

Figure 1. Cross sectional view of the Injector.

ionizer source emitting K^+ ions. Beam extraction is performed during the Marx generator flattop by pulsing the source voltage positive with respect to the dome.

The Marx generator consists of 38 stages of a two-section network that produces a flat-top voltage pulse. It has recently been upgraded by refurbishing the trays, and by modifying the circuit through the introduction of magnetic coupling between the two sections. The modification increased the flat-top pulse length from 3.9 μs to 5.2 μs. The extractor pulse, which delivers a pulse swing of up to 160 kV (from –80 kV to +80 kV) applied to the source with respect to the extraction electrode, should be shorter than the Marx generator flat-top because of jitter and time-of-flight considerations. It was originally 2.0 μs long, but has been extended to 3.0 μs, and modifications are currently underway to further extend the extractor pulse to 4.5 μs. The increased pulse length will provide the opportunity to study beam transport over pulse lengths more representative of a fusion driver, which may be as long as 20 μs.

Two types of ion sources were using in this investigation: a K^+ aluminosilicate source, and a K^+ contact ionizer source. The aluminosilicate source was prepared by melting a thin layer of aluminosilicate loaded with potassium to form a smooth coating on the porous tungsten substrate of the source [4]. The contact ionizer source was prepared by applying a solution of K_2CO_3 on the bare porous tungsten substrate [5]. Baking at a temperature in excess of 500°C dissociates the carbonate, and releases CO and CO_2. The potassium atoms remain on the substrate and are available for emission as ions.

The Injector is instrumented with a Rogowski coil and two large Faraday cups for transported beam current

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measurements, and a slit-scanner diagnostic for emittance measurements. A multiple Faraday cup array (FCA) is utilized to examine beam optics at the diode. It consists of an array of small Faraday cups (1-mm diameter entrance aperture) arranged in two orthogonal rows mounted in a single movable assembly. The collectors are staggered in radius with a center to center separation of 3.8 mm, beginning at 1.9 mm in the nominally horizontal direction, and at 3.8 mm in the nominally vertical direction. Note that there is no collector in the array precisely on axis. The assembly can be rotated and moved along the beam axis inside the ESQ column. Figure 2 shows the configuration of the collectors on the FCA. In addition beam image patterns on Kapton films have been obtained at several locations.

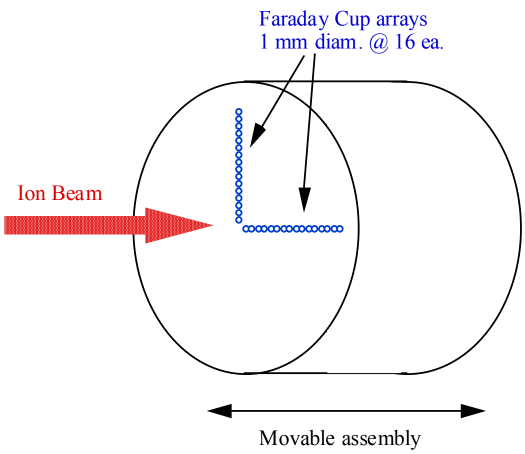

Figure 2. Schematic diagram of the 32-channel Faraday cup array.

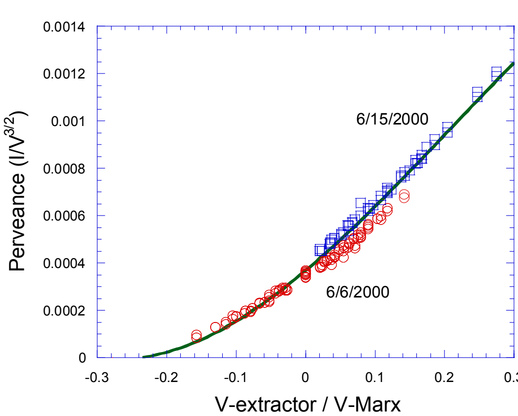

Figure 3. Comparison between measured and predicted (EGUN) beam current in the diode for the 10-cm diameter aluminosilicate source. Dates of measurements are indicated.

3 BEAM IN DIODE

Measurements of the beam perveance ($I/V^{3/2}$) made with a large Faraday cup at the end of the diode are shown in Figure 3. These are measurements of the beam current as the accelerating voltage [V-Marx] and the extraction voltage [V-extractor] were varied over as wide a range as possible. Only the diode section was energized in this set of measurements. The normalized current (perveance) under these conditions should fall on the theoretical curve indicated. The measured beam currents in this test were in a very wide range, from 27 mA to 764 mA, as accelerating voltages ranged from 240 kV to 706 kV. They show good agreement with the EGUN prediction, as shown. The agreement provides clear evidence that the diode was operating at the space charge limit over a wide operating range.

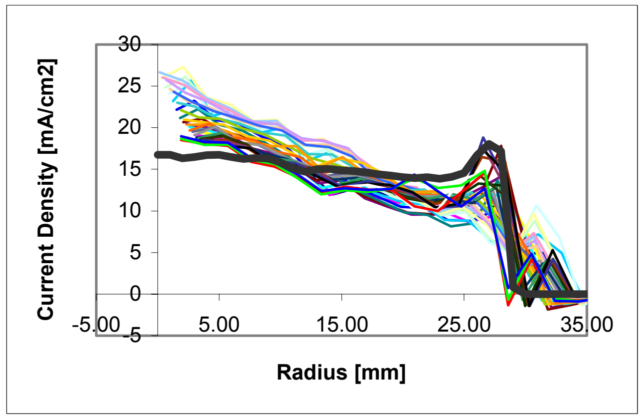

Figure 4. Measured beam profiles for an 80-kV equivalent (extractor) beam at an axial distance of 2.54 cm, and EGUN predicted profile (thick black curve).

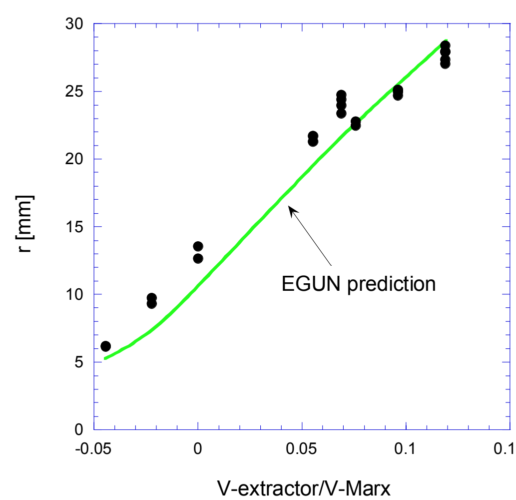

Figure 5. RMS beam sizes $2\langle x^2\rangle^{1/2}$ and $2\langle y^2\rangle^{1/2}$ for measured beam profiles, compared to EGUN predictions.

A series of two dimensional scans of the beam profile at the exit of the diode were made. Beam current density measurements were taken at 36 angular positions and 16 radial positions to create the map. All 36 radial profiles for a scan under typical operating condition are shown in Figure 4.

A summary of RMS beam sizes is shown in Figure 5, and compared with EGUN prediction of RMS beam size at the same axial location. The measured and calculated beam sizes follow the same trend. The residual disagreements may be related to disagreement in the current density profile, and small variations in geometry, for example effects of thermal expansion.

4 BEAM AT END OF ESQ SECTION

A Kapton film image of the beam taken at the end of the ESQ is shown in Figure 6 for an 80-kV-equivalent beam. Note that the profile of the beam in this case has a pronounced rim, and the beam been distorted into a rectangular shape. Both effects are seen in simulations, and are attributed to aberrations in the diode, and the energy effect, respectively. The cause of the energy effect is that ions at a given axial location within the quadrupole channel have variable energies, depending on their relative proximity to the negative and/or positive electrodes. Variations in beam energy lead in turn to a spread in betatron motion, which results in a kinematic aberration of the beam [2]. Operation with lower beam current yields much less pronounced distortions in the beam profiles. Aberrations are significantly reduced and the beam spot is nearly elliptical.

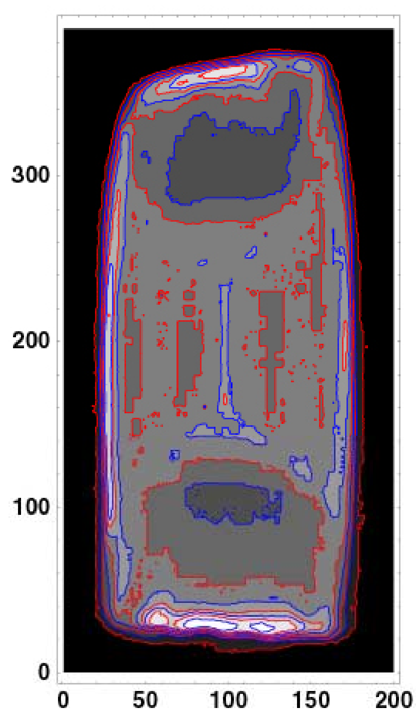

Figure 6. Contour plots of beam intensity from a Kapton film exposed by the beam, showing a raised rim and a rectangular shape. Intensity, indicated by the grayscale, is lowest for black and greatest for white. The internal structure in the image is due to an after-pulse, not the main beam pulse. The beam dimensions are roughly 5 cm x 10 cm. The scale is in pixels; each pixel is 25 μm in size.

Double-slit vertical phase space measurements at the end of the ESQ are shown in Figure 7. The profile has been rotated to remove the overall angular divergence of the beam at this point. The distortion in phase space from a purely elliptical shape indicate the emittance growth through the entire accelerating structure. Results of a PIC simulation code (WARP-3D), processed in the same way, are shown for comparison.

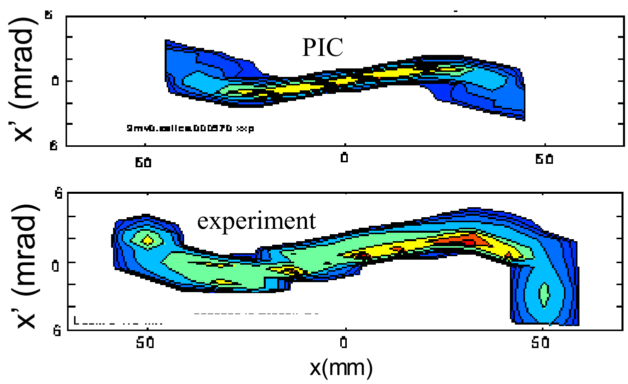

Figure 7. Transverse phase space calculated (PIC) and measured at the exit of the ESQ injector for 80 kV (equivalent) extractor voltage.

5 DISCUSSION

The 2-MV Injector has been refurbished, upgraded, and characterized under conditions appropriate for use as the injector for HCX. A retrofit [6] aimed at decreasing beam aberrations and modifying beam parameters for injection into the matching section is nearing completion.

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