HIGH VOLTAGE, HIGH CURRENT, LONG PULSE ELECTRON BEAM INJECTOR FOR DARHT

E. Henestroza, S. Yu, S. Eylon
Lawrence Berkeley National Laboratory, Berkeley, CA 94720 USA,
B. Carlsten
Los Alamos National Laboratory, Los Alamos, NM 87545 USA

Abstract

An injector design for the long pulse option for the second axis of the Dual-Axis Radiographic Hydrotest Facility (DARHT) has been studied. This design is based on the LBNL Heavy Ion Fusion Injector technology. The proposed injector consists of a single gap diode extracting electrons from a thermionic source and powered through a high voltage ceramic insulator column by a Marx generator. The key issues in the design are the control of beam quality to meet the DARHT 2nd axis final focus requirements, to minimize high-voltage breakdown risks, and to fit the injector structure within the available space. We will present the injector conceptual design as well as beam dynamics simulations in the diode and in the injector-main-accelerator interface.

1 INTRODUCTION

A high voltage (2 to 4 MV), high current (4 kA), long pulse (2 µs flat-top) electron beam injector for a linear induction accelerator for flash-radiography applications has been under study at LBNL. Based on LBNL Heavy Ion Fusion Injector technology [1] and beam dynamics simulations we have studied an injector that will mantain the beam quality, minimize high voltage breakdown problems, and have the required reliability. Figure 1 shows the main components of a 3 MV electrostatic injector.

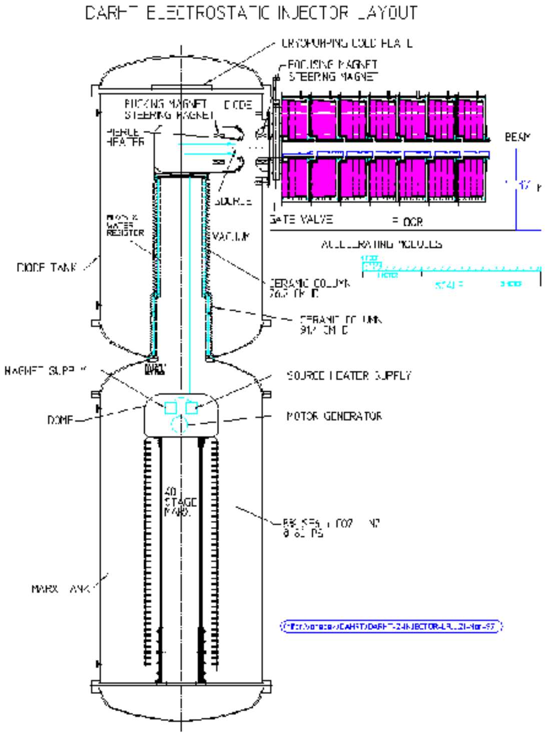

Figure: 1 Main components of a 3 MV electrostatic injector.

2 HIF 2 MV INJECTOR

A driver-scale injector for the Heavy Ion Fusion Accelerator program has been in operation at LBNL for several years. Figure 2 shows a schematic of the 2 MV Injector that has exceeded the design goals of high voltage (> 2 MV), high current (> 0.8 A of potassium ions) and low normalized edge emittance (< 1 π mm-mr). The injector consists of a 750 keV pre-injector diode followed by an electrostatic quadrupole accelerator (ESQ) which provides strong (alternating gradient) focusing for the space-charge dominated beam and simultaneously accelerates the ions to 2 MeV. The injector is powered by a 2 MV Marx generator which consists of 38 trays with parallel LC and RC networks to produce a 4 µs flat-top pulse to accommodate the entire ion beam plus the transit time across the injector. Pulse lengths of about 1.5 µs and energy flatness of around ±0.15% have been achieved.

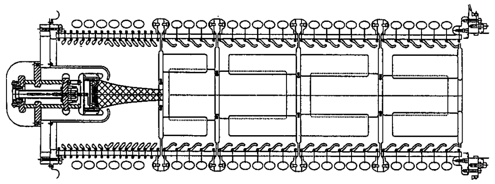

Figure: 2 Schematic of the 2 MV HIF Injector.

The main design effort for the HIF Injector was concentrated on minimizing breakdown risks; the design was based on breakdown data from previous (ions and electron) injectors as well as breakdown tests performed on several of its components. Other important features of the 2 MV HIF Injector are reproducibility and energy flatness. These fatures make this injector a highly reliable machine.

The 3 MV long pulse electron beam injector design is based on the HIF 2 MV Injector operating experience regarding breakdown issues, reproducibility and energy flatness.

0-7803-4376-X/98/$10.00

3 MARX GENERATOR AND INSULATING COLUMN

The 3 MV pulse generator design is based on the LBNL HIF 2.3 MV MARX. It consists of 55 identical pulse forming network stages connected in series to generate the output pulse and is connected to the insulating column through a dome. The MARX and the inside of the insulating column are contained in pressurized SF_6. The 100 inches insulating column consists of 50 ceramic brazed rings with an ID of 30 inches and an OD of 32 inches. The outside of the column is in vaccuum and is protected from stray electrons and heat by copper shields. The field stress along the column is less than 50 kV/cm in vaccuum and less than 200 kV/cm in SF_6. MOV's and water resistors are used to by-pass excess MARX energy during a breakdown. A hydraulic motor generator placed inside the dome provides, at the pulse 3 MV level, the heating power for the source (around 4 kW) and current for the focusing magnet.

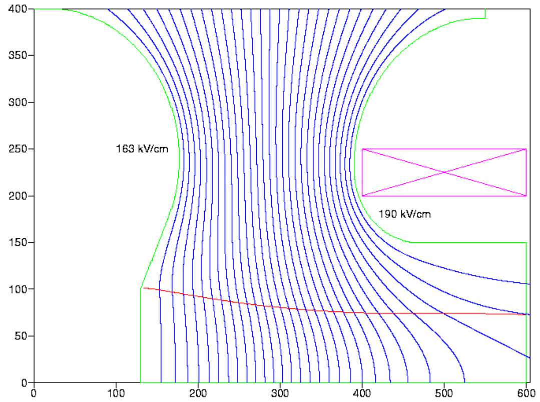

Figure: 3 Electron beam envelope and field equipotential lines as calculated by EGUN.

4 THE 3 MV ELECTRON DIODE

The electron beam is generated in a 3 MV diode. It consists of a thermionic source surrounded by a Pierce electrode and focused by a solenoid located at the anode entrance. A bucking coil is located close to the source to zero the axial magnetic field in order to minimize the initial canonical angular momentum of the beam; outside the magnetic field this canonical angular momentum would be transformed into beam emittance.

The beam dynamics inside the diode has been studied using the electron trajectory computer code EGUN [2]. Figure 3 shows the electron beam envelope and field equipotential lines as calculated by EGUN for the 3 MV case.

In order to have a reliable machine the diode design has to minimize breakdown risks. This requirement translates into a design with maximum current extraction for a given maximum field stress. From final focus requirements at the end of the machine, the beam quality has to be controlled and the normalized emittance be maintained under 1000 π mm-mr.

For a given field stress limit, maximum current extraction is obtained from cathodes surrounded by a flat shroud as compared to diodes incorporating Pierce electrodes. On the other hand, the beam quality is better controlled by a Pierce electrode; flat shrouds produce hollow beams whose normalized emittance grow as being transported and accelerated along the induction linac. A compromise between the two conflicting requirements is to design the diode with a Pierce electrode assuming the maximum voltage holding capability that can be obtained using special surface handling procedures; this peak field is around 165 kV/cm on the cathode side of the diode and above 200 kV/cm on the anode side. For this design the emittance at the end of the diode is under 1000 π mm-mr as calculated by EGUN.

5 BEAM DYNAMICS ALONG THE LINAC

A two-dimensional particle-in-cell (PIC) slice (x-y) code [3] has been used to study the transverse beam dynamics of the electron beam generated at the injector as it is transported and accelerated along the induction linac.

The main linac consists of 87 induction cells each providing 200 kV of acceleration. Each cell contains a solenoid used to focus the electron beam. Figure 4 shows electron trajectories for an EGUN simulation of the diode and the first 7 induction cells; the beam quality is preserved. In Figure 5 it is shown the beam envelope and the normalized beam emittance along the induction linac for a complete transverse dynamics run using SLICE, which takes into account all the external fields as well as the space charge. No emittance growth is predicted.

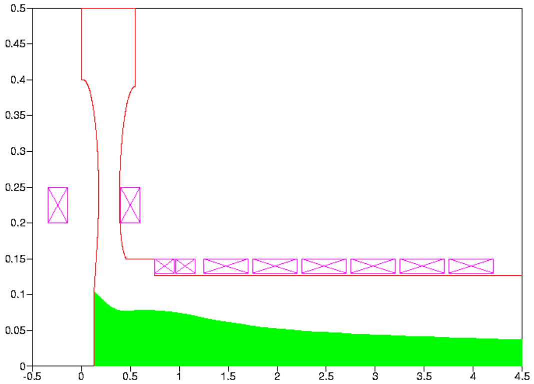

Figure: 4 EGUN simulation of the electron beam from source to the end of the first acceleration section (7 cells).

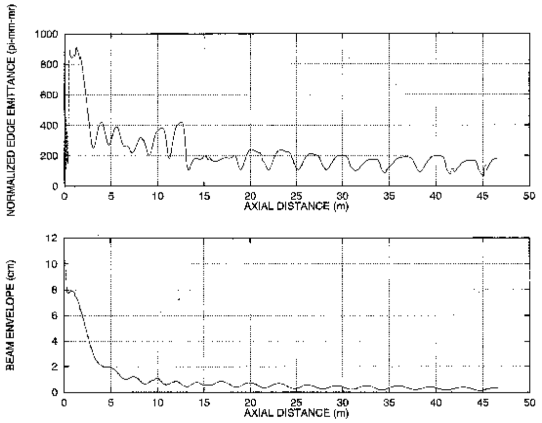

Figure: 5 Particle in cell calculation of the transverse beam dynamics along the induction linac.

6 ACKNOWLEDGEMENTS

This work was performed under the auspices of the U.S. Department of Energy under contract AC03-76SF00098. We thank Glen Westenskow for advice and David Vanecek for technical support during the design period.

REFERENCES

[1] E Henestroza, "Injectors for Heavy Ion Fusion", invited talk, 11th International Workshop on Laser Interaction and Related Plasma Phenomena, Monterey, CA, October 25-29, 1993. AIP Conference Proceedings 318, Ed. G.H. Miley, pp 577-582.

[2] W.B. Herrmannsfeldt, "EGUN- An electron optics and gun design program," SLAC-Report-331, 1988.

[3] B. Carlsten, "The PIC-xy 2-D SLICE code", private communication.