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PROGRESS REPORT ON TESTING OF A 100-kV 125-mA DEUTERON INJECTOR*

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Abstract

The Linear Accelerator to be used for the Fusion Materials Irradiation Test Facility (FMIT) will require an injection energy of 100 keV at a dc current level of 125 mA. Studies are being made on a pre-prototype version of this injector, including performance tests of both a single aperture reflex-arc ion source and a cusp-field source. A single stage, high-gradient extraction system is used prior to mass analysis in a 90° bending magnet. A two-stage beam steering device to measure beam emittance under full beam power has been designed and constructed. To avoid production of neutrons, all prototype tests are run with H_2^+ ions rather than D^+ ions.

Introduction

The FMIT Facility consists of a 100-mA dc, 35-MeV deuteron linac with a liquid-lithium target. Its purpose is to generate a high flux of high-energy neutrons for radiation damage tests on materials that might be used to fabricate a thermonuclear fusion reactor. The deuterons from the beam undergo a nuclear stripping reaction in the target and the resultant neutron flux of 10^{15}n/cm^2-s fills a volume[1] of approximately 5.6 cm^3 and has an energy spectrum centered near 14 MeV. The injector will have to provide a beam of D^+ ions with a 125-mA current at an energy of 100 keV with a normalized beam emittance of 0.1 mrad-cm. To reduce radiation problems, experiments on the injector pre-prototype and prototype are being done with H_2^+ as the principal ion species rather than with D^+. It is desirable to have the monatomic species ratio as large as possible, preferably 80% or higher, to facilitate achieving the rather high single-species current required from the source.

Activities have concentrated on design, construction, and testing of the injector pre-prototype. Two different ion sources are being used alternately with a single aperture, single gap extraction system. A double-focusing bending magnet steers the beam into the beam line while selecting the desired ion species. Current measurements are made with a calorimeter. A two-stage magnetic-scanning emittance-measuring system has been built that will allow emittance measurements under full beam power.

Injector System

The injector pre-prototype is shown in Fig. 1. The vacuum system[2] is described in a paper to be given at this conference. The ion source shown in this figure is a version of the Lawrence Livermore SARA or Osher source.[3] This source was designed to provide a beam with 150 mA of 75-83% D^+ at 20-kV extraction potential and with a normalized emittance of 0.02 mrad-cm.[3] Because the design parameters of the source were so close to those required by FMIT, it was chosen as the logical starting point for injector development.

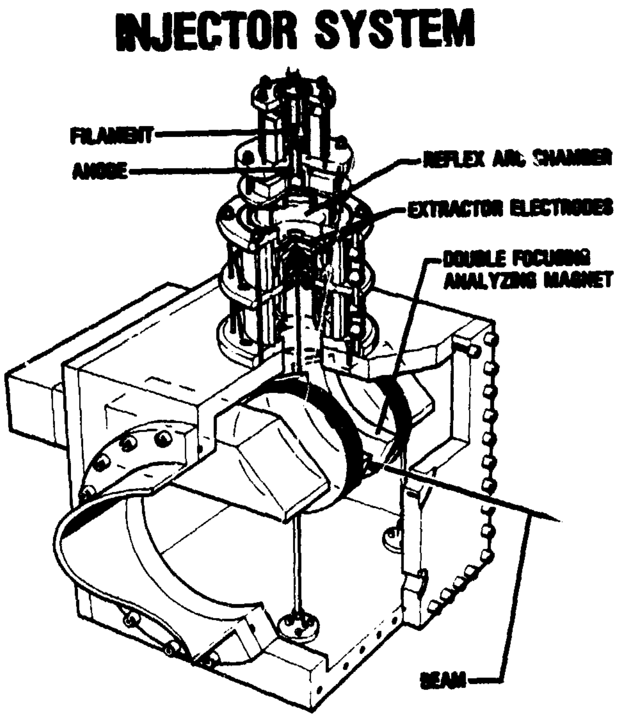

Fig. 1. FMIT injector system.

A "picket fence" or cusp-field chamber has been constructed and is being used as a replacement for the reflex-arc chamber of the Osher source and as an independent ion source. The cusp-field chamber is based on a Culham design[4] and consists of a water-cooled cylindrical anode (18-cm diam, 31-cm long) with thirty 25.4-cm-long ceramic bar magnets arranged axially around the outside anode wall to generate a periodic cusp magnetic field on the inside of the anode. A steel tube is fitted to the outside of the magnet array to complete the magnetic circuit and to increase the cusp field inside the chamber. The tube also forms the outside of the water jacket. The cusp field reaches a maximum of 760 G at the inside anode wall and drops exponentially to 130 G, 1 cm inside the anode wall. When the chamber is being used as a replacement for the reflex-arc chamber of the Osher source, a discharge is run from the Osher anode to the cusp anode while the end plates of the cusp chamber are kept at ground (negative with respect to both anodes) to reflect electrons. If, however, it is being used as an independent source, a filament mounting plate is installed at the top end of the chamber, opposite the extractor. The cusp field prevents electrons from moving directly to the anode and hence increases their lifetime in the chamber. The increase in electron lifetime should increase ionization efficiency and the large number of thermal electrons should increase the dissociation rate that raises the monatomic species ratio. Measurements by others indicate that this type of source provides a beam with low noise, high-current density and low emittance.(5)

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Westinghouse/Hanford Engineering Development Laboratory employee working at the Los Alamos Scientific Laboratory.

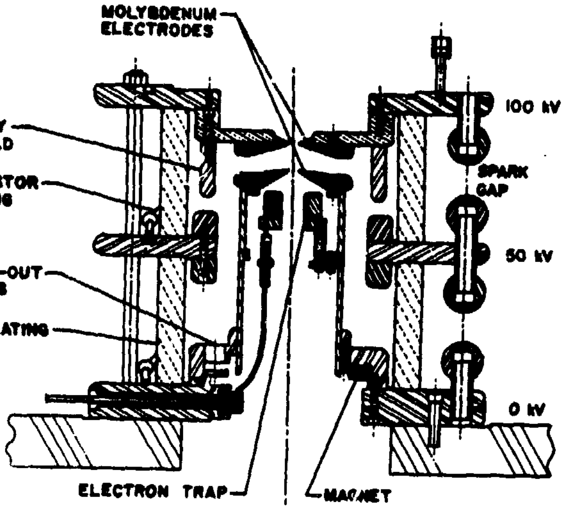

Fig. 2. 100-kV single-gap extractor.

The 100-kV extractor is a single-gap accelerating column, as shown in Fig. 2. It consists of two 20.3-cm-ID by 12.7-cm-long nylon insulating rings sandwiched between three annular 38.1-cm-OD stainless steel plates. Reentrant geometry is used at the inside corners of the insulating rings to keep fields low at these critical points. Voltage grading is provided by resistors and arc protection is furnished by external spark gaps.

Molybdenum electrodes are used, the exact shape based on aberration-free Pierce design modified by the Sandia-developed SNOW code.[6] This initial design utilizes an aperture (1.13-cm diam) whose area is one-half that intended for the FMIT extractor. Design current for this half-area aperture is 100 mA at 100 kV, which results in the same current density as required for the FMIT extractor.

A 1.3-cm-thick stainless-steel ring around the electrodes and other thick sections shield the insulating rings from X-radiation (bremsstrahlung) that originates in the beam region of the extractor. This radiation causes a significant increase in high-voltage-breakdown problems by charging the insulators photoelectrically. The electrons that generate the bremsstrahlung come from two sources: beam ionization of background gas in the acceleration gap and electrons which backstream from the region below the ground electrode of the extractor upward through the acceleration gap. The first source has been reduced by installing sixteen 1.9-cm-diam pump-out holes, shown in Fig. 2, which reduce the background gas pressure. Addition of these holes introduces a new path for backstreaming electrons and these electrons are stopped at each hole by a transverse 500-G magnetic field generated by permanent magnets. The second source is reduced by either an electrostatic or a magnetic electron trap located in the beam line, as shown in Fig. 2. When the magnetic trap is used, the slip-on annular magnetic assembly can provide either a 30 G or 150 G transverse field.

After acceleration the beam passes through an analyzing magnet that has a 7.6-cm parallel gap with a 2.7-kG field and 25.2° slanted edges. The bending radius is 13.14 cm. This magnet steers the desired species into the beam line.

An emittance measuring system has been constructed and is shown in Fig. 3. The beam is first swept by an x-y steering magnet across a small circular orifice (0.01-cm diam) that is mounted at the end of a double-walled water-cooled copper cone designed to dissipate the 12.5 kW of beam power. A 6-W beamlet passes through the orifice to a second magnet that sweeps the beamlet across a 0.01-cm-wide rectangular slit. The second magnet and slit are mounted together as a rotatable assembly so that both x and y emittance measurements can be taken without shutting off the beam. The first scan defines the (x,y) position of the point in the beam cross section at which the measurement is being made. The second scan defines the dx/dz or dy/dz of the beamlet at that point by measuring the angular divergence of the beamlet.

Test Results

To determine the magnitude of gas-phase ionization, bremsstrahlung measurements were made at 75 kV before and after adding the pump-out holes. At 50-mA

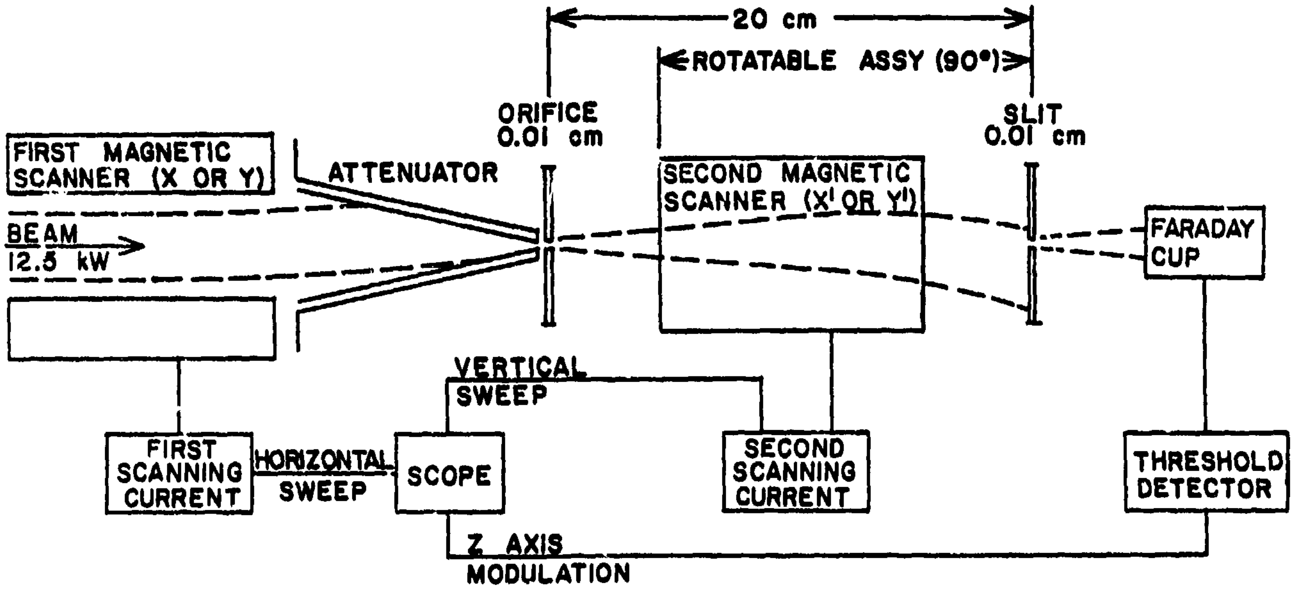

Fig. 3. Emittance measuring system.

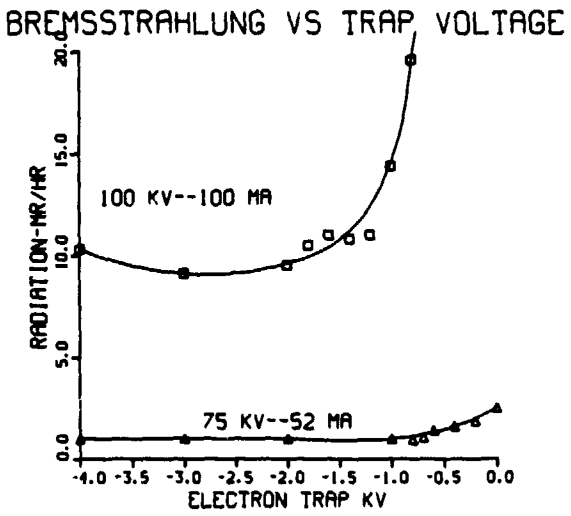

Fig. 4. Radiation level vs electron-trap voltage.

extracted current, 14 mR/h was measured initially at a distance 1.2 m from the source as compared to 1 mR/h after the holes were added. Radiation levels scaled linearly with extracted current. Electron-trapping magnets initially installed between the pump-out holes were too weak; electrons backstreaming to the mid-plane plate caused unequal voltage division across the column resulting in sparkdown. Stronger magnets producing a 500-G transverse field were substituted, completely eliminating this problem. The stray field from this array at the beam edge is less than 1 G.

Both magnetic and electrostatic versions of the beam line electron trap were tested. The magnetic trap with 30-G transverse field was too weak to stop backstreaming electrons and the stray field from the 150-G version caused a drastic reduction in extracted current. The magnet assembly was removed and tests were conducted with the electrostatic trap. The results are shown in Fig. 4. Optimum electron-trap settings are -0.8 kV at 75 kV and -1.6 kV at 100 kV. An extracted current of 100 mA at 100 kV has been obtained with the Osher source, meeting design current requirements for the half-area aperture. Less than 1 or 2% of the extracted current is caused by back-streaming electrons.

Under these conditions the beam divergence was somewhat larger than expected. This effect could be due either to loss of space-charge neutralization caused by the electron trap or to uncertainties in the optical design. The electron-trap geometry is being changed in an attempt to reduce the divergence.

Both the magnetic electron trap and the bending magnet created stray magnetic-field problems. The bending magnet reduced the extractable current by 30-40%. Its poles are approximately 30 cm from the plasma-extraction surface; however, it is not clear yet whether the stray fields are affecting the source plasma or the extractor itself. Installation of a large, conical, mild-steel shield around both these regions did not eliminate the problem. Modifications are underway to increase the magnetic shielding of both regions by replacing some pieces in the extractor system with mild-steel parts.

The cusp chamber was tried as a replacement for the reflex-arc chamber of the Osher source. Initially, no more than 20-30 mA of current was extracted. Filaments have been installed to allow use of the cusp chamber as an independent ion source. The four filaments are nickel-gauze strips 1.3-cm wide mounted in a square array between four posts which are on a 10-cm-diam bolt circle. The flat of each filament faces the anode. In this configuration the source is remarkably easy to operate. Only three parameters need to be controlled: gas flow rate, filament current, and arc current. The arc is easy to strike and very stable. The source is automatically shielded against external magnetic fields by the steel outer wall. When the bending magnet was turned on, the extracted current dropped by only 10% as compared to 30-40% with the Osher source. The low extracted current implies that the ion density must be increased either by increasing the discharge current or by reducing plasma wall losses. Additional power supplies are being installed to increase the arc current and additional magnetic confinement is being added to the end plate holding the filaments. An interesting result involving wall losses was found by reducing the size of the filament supports. Some long supports, designed to position the filament closer to the extraction aperture, were shortened radically. The percentage increase in extracted current could be accounted for by the ratio of surface area removed to the total chamber surface area.

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