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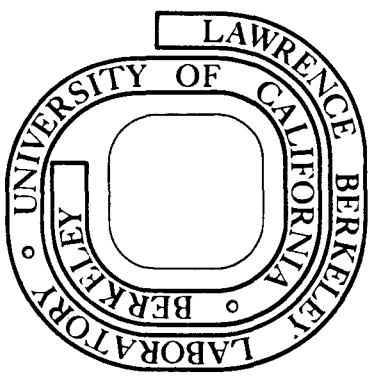
W. R. Baker, K. H. Berkner, W. S. Cooper,
K. W. Ehlers, W. B. Kunkel, R. V. Pyle,
and J. W. Stearns

April 18, 1973

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DESIGN AND OPERATION OF INTENSE NEUTRAL BEAM SOURCES*

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ABSTRACT: Neutral beam sources to inject up to 50 A equivalent current at 20 keV into mirror plasmas are described.

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One of the more promising methods for the production, heating, and maintaining of plasmas, and for diagnostics of controlled fusion experiments is the injection of very large currents of energetic neutral beams. We describe the design and performance of neutral beam sources for the Lawrence Livermore Laboratory 2XII and BBII experiments. The major efforts are summarized in the Table.

Major LBL Neutral Beam Activities

Expt.	Nominal Max. Voltage	Nominal Pulse Length	Gas	Equiv. Neutral Current Into Plasma	Total Extracted Ion Current	Total Neutral Equiv. Current	Status
2×II	20kV	30ms	D_2	~10A	~16A	~18A	4 Built & Tested
BB II	5 kV	10 S.	H_2	~2A	~5A	~6A	Partly Built
2×II	20kV	10ms.	D_2	~50A	~80A	~90A	Partly Built

20 kV, 10 A (EQUIVALENT) D^0 BEAM FOR 2XII EXPERIMENT. Specifications: 10 A (equivalent) neutral deuterium into 2XII at 20 kV accelerating voltage with a 30 msec pulse length. The plasma target dimensions are 10 x 20 cm at 330 cm from the ion source ($\pm 0.9^\circ$ x $\pm 1.8^\circ$). We have also provided for the possibility of chopping the beam at a frequency of 10 kHz, or rapidly modulating the beam energy. The system consists of a large plasma source, a multiple-aperture accel-decel extractor structure that was designed with the aid of a digital computer and a closely coupled charge-exchange cell. Figure 1 shows a drawing of the assembled extractor and plasma source.

*Work performed under the auspices of the U. S. Atomic Energy Commission.

The plasma is produced by a pulsed (30 msec), low-pressure, high-current discharge [1] between a ring of 20 or 28 tungsten filaments (ϕ = 0.5 mm, 11 cm long) and an annular anode. No externally applied magnetic fields are used. Deuterium gas is pulsed into the arc chamber 1 sec after the filaments are turned on, and arc power is applied ~ 10 msec later. The resulting plasma is free of noise and is uniform to better than ±10% over a 10 cm diameter. Arc current of about 800 A is required for operation at 20 kV, at which voltage the deuterium ion current density extracted from the plasma is 0.5 A/cm^2.

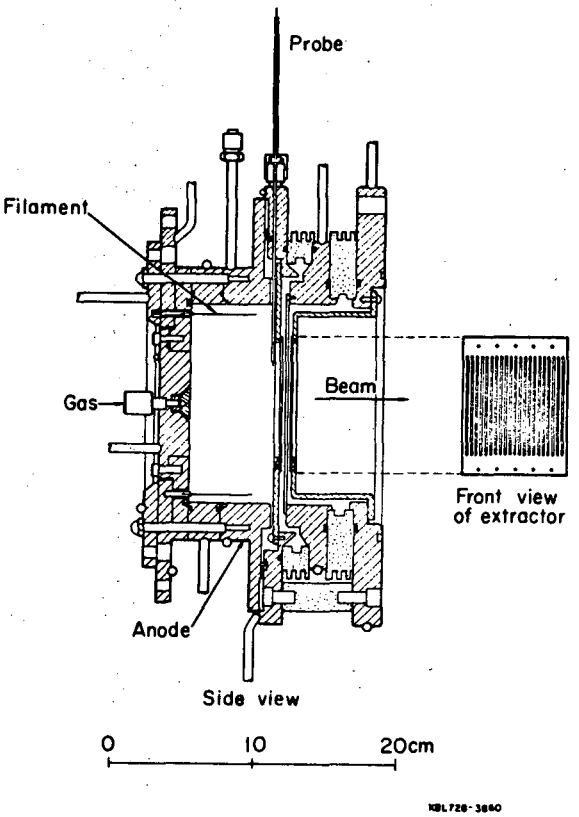


Fig. 1. Cross section of plasma source and extractor assembly.

The extractor is a multiple-aperture accel-decel-design employing slots [2]; a cross section of a single slot, with calculated equipotentials and ion trajectories is shown in Fig. 2. There are 21 slots in the beam-forming electrode, each 2 mm wide and 7 cm long, spaced 3.3 mm center-to-center, filling a square array 7 cm on a side. The extractor is constructed of copper, with epoxy insulators.

Extractor voltage is applied 5 msec after the plasma arc begins. The accelerated ion beam undergoes charge exchange in a gas cell adjacent to the extractor; the gas from the source is sufficient for this purpose. No magnetic focusing is used.

Figure 3 shows the performance of our first neutral beam source in producing deuterium beams in the energy range of 10 to 20 keV. The figure shows for each extraction voltage (the voltage between the first and second electrodes) a range of extracted beam currents. We show as an upper limit to the extracted beam current the high-voltage power supply drain and, as a lower limit,

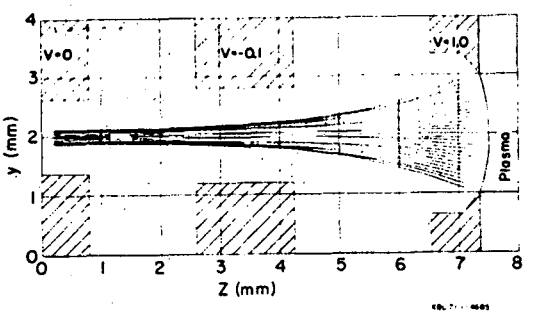


Fig. 2. Cross section of a single slot in the extractor, showing relative electrode potentials and calculated ion trajectories and equipotentials

that current minus the current to the second electrode. The extracted current exhibits the expected $V^{3/2}$ dependence on extraction voltage. Also shown are the calorimetrically measured currents (total beam, ions plus neutrals) reaching a 10 x 20 cm target at 330 cm (circles) and similar measurements for a 20 x 40 cm target (x's). It is apparent that the beam divergence decreases with increasing beam energy.

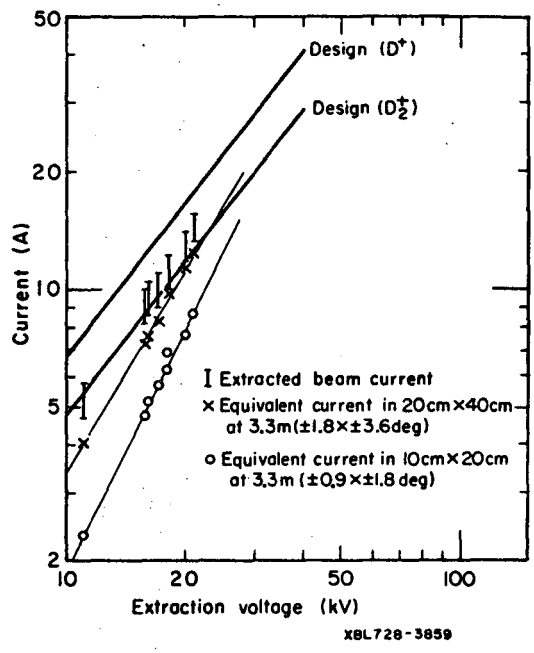


Fig. 3. Current (actual or calorimetric equivalent) versus extraction voltage for operation with deuterium. The decelerating voltage was 1.1 kV. The two lines labeled "Design" were obtained from the calculated perveance; the thin lines connect data points.

The latest model of this source has an extracted current of about 16 A at 20 kV, with a total equivalent current of 9.5 A to the 10 x 20 cm target. About 90% of the beam energy is in neutral particles. Measurements of the beam composition for typical operating conditions showed that 44% of the neutral particles were full-energy D^0, 23% half-energy D^0, 27% 1/3-energy D^0, 2% full-energy D_2^0, and 4% 2/3-energy D_2^0. From these measurements we deduce that the deuterium nucleus equivalent current into the 2XII 10 x 20 cm target is about 10.5 A. From known cross sections, we deduce that the ion species extracted from the source (before neutralization) are about 75% D^+, 18% D_2^+, and 7% D_3^+. A calculation of the source perveance for this mixture gives good agreement with experiment.

Measurements of the beam profiles with a 32-channel calorimeter showed that the beam divergence was less in the plane of the slots than perpendicular to the slots, as expected [2]. In all cases, when the current to the central portion of the calorimeter was maximized by varying the plasma density, the beam profile in either plane could be fitted by a Gaussian folded with a rectangular source function. The 1/3 half-widths of these Gaussians (corrected for the contribution of the finite source) are shown in Fig. 4. Although the angular divergence is small, especially in the direction parallel to the long dimension of the extractor slots, it is important to reduce the divergence more. There are many possible causes of beam divergence: lens aberrations, potential and density gradients in the plasma, finite ion temperature, electric fields in the

plasma produced in the charge exchange cell, perturbations of ion trajectories at the plasma-extractor interface, gas scattering, mechanical imperfections, etc. We are attempting to estimate the magnitude of each effect and, if possible, reduce it.

Mechanical imperfections and misalignments in the extractor assembly result in broadening or steering of the beams. We find that a translaction of the first (next to the plasma) of the extraction electrodes by 0.1 mm in a direction perpendicular to the long axis of the slots will change the angle at which the accelerated beam emerges by 3.5°.

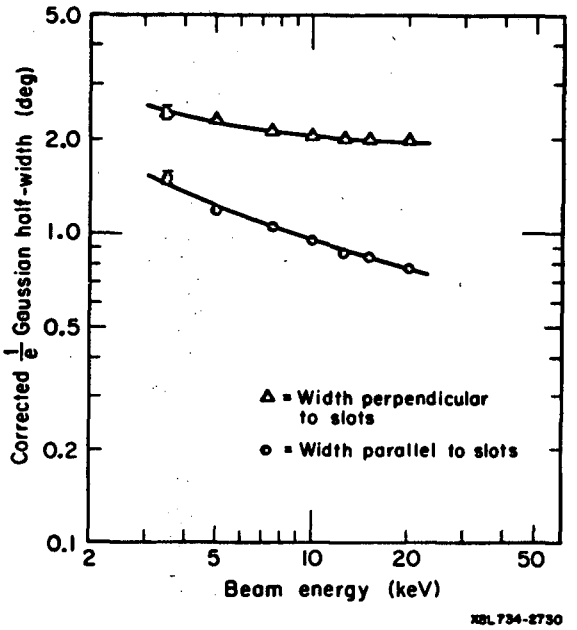


Fig. 4. Corrected 1/e Gaussian half-widths.

This effect means that careful construction and alignment of the extractor is required, but also allows us to construct a large area plane extractor from which beams converge toward the plasma target. We use this effect in the design of the 50 A D^0 source.

LOW-VOLTAGE, 10 sec BBII SOURCE. Specifications: 1/2 A (equivalent) neutral hydrogen into BBII at 2 kV accelerating voltage, 1 A at 3 kV, and 2 A at 5 kV, with a 10 sec pulse length. This source is designed to extract at 11 kV and decelerate the 0.25 A cm^{-2} ion beam to the desired energy before neutralizing it. A water-cooled slotted extractor will be used. The plasma source is built and tested; extractor design tests are in progress.

2XII 50 A D^0 MODULE. Specifications: 50 A (equivalent) neutral deuterium into 2XII at 20 kV accelerating voltage, with a pulse length of 10 msec, and a compact design, to permit use of several adjacent modules for higher current. The design is similar to that of the 10 A D^0 2XII source, except that the beam is extracted from a 7 x 35 cm electrode array. Adjustments of the relative electrode positions will direct the beams from each of five 7 x 7 cm arrays toward the 2XII plasma. The construction of this neutral beam source and associated electronics is in progress.

[1] K. W. Ehlers and W. B. Kunkel, Proc. Second Int. Conf. on Ion Sources, Vienna, 1972, p. 259.

[2] W. S. Cooper, K. H. Berkner, and R. V. Pyle, ibid., p. 264.

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