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Lawrence Berkeley Laboratory University of California/Berkeley

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PERFORMANCE OF A DEVELOPMENTAL 120-keV, 10-A DEUTERIUM (14-A HYDROGEN) NEUTRAL BEAM SYSTEM*

K. H. Berkner, W. S. Cooper, K. W. Ehlers and R. V. Pyle

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

We have recently operated the LBL 120-keV neutral beam test facility on deuterium. This facility consists of a large (170,000 ℓ) vacuum system, a plasma source, a multiple-aperture electrostatic accelerator structure, an ion sweep magnet, ion and neutral beam dumps, and a computer diagnostic and control system. The total length of the beamline is about 8.5 m. Operation of this test facility on deuterium has produced beams with an energy of 120 keV, a total (ion plus neutral) beam current of 10 A, and a pulse length of 0.5 sec. The beam profile at the location of the dump is bi-gaussian, with 1/e half-widths of about 1.28 and 0.42 degrees. Deuterium operation has been very limited because of the high neutron production rate (about 10^{11} sec^{-1} when the beam is on) and the lack of radiation shielding around the facility.

I. Introduction

The injection of intense, 80-keV H^o- or D^o-beams is planned for the Doublet III-tokamak and the MFTF-mirror experiments for plasma heating; for the Tokamak Fusion Test Reactor (TFTR), 120-keV D atoms (20 MW in 0.5-sec pulses at 5-minute intervals) will be injected into a tritium plasma to produce two-component d-t reactions. The principal components of these neutral-beam injection systems are shown schematically in Fig. 1.

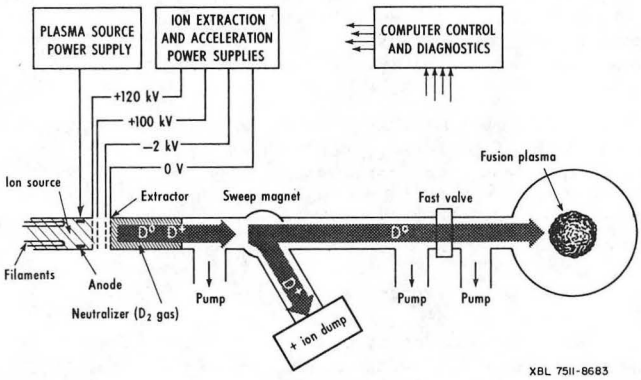

Figure 1. Schematic of a typical neutral-beam injection system.

The system operation is as follows: A deuterium plasma is created in the plasma generator by means of a high-current discharge. Ions from this plasma are accelerated in a carefully designed multi-electrode structure. The ions then pass through a neutralizer containing deuterium gas, and a fraction becomes neutralized by charge-exchange collisions. Remaining ions are removed from the beam by the sweep magnet; otherwise, the various reactor magnetic fields would bend the ions into surfaces near the entrance port, possibly releasing gas bursts or melting the surfaces. The considerable power in this ion beam must be handled by the ion-beam dump. The vacuum pumps distributed along the beam line remove most of the gas emerging from the neutralizer and the ion-beam dump and must maintain the pressure between the sweep magnet and the entrance port at a sufficiently low value that very little of the neutral beam is reionized. Well-regulated power supplies are required to assure good beam optics; to minimize accelerator damage when a spark occurs, the power supplies must also be capable of rapid turn-off with a minimum of stored energy (e.g. in cable capacitance). Optical, mechanical, and electrical sensors determine the condition and performance of the neutral-beam system and permit the control system to adjust the power-suply voltages and to shut down the system if a malfunction occurs.

The LBL 120-keV Neutral-Beam Test Facility[1,2] is used for the development and testing of neutral-beam-system components. It has two beam lines and associated power supplies: (A) a 150-kV, 20-A, 0.5-sec power-supply system[3,4] to test small-area injector modules (plasma source and accelerator), and (B) a 120-kV, 70-A, 30-msec power-supply system to test full-scale modules for short pulses. The beam-diagnostic system for these beam lines is described in Ref. 5.

In this paper we describe the operation of a 120-kV, 0.5-sec injector module which, from an 8- x 10-cm accelerator-grid array, produces ∿14 A of hydrogen ions or ∿10 A of deuterium ions. This module was used to test the design concepts of the 10- x 40-cm, 120-kV, 65-A, 0.5-sec TFTR module[6-8] which is currently under test.

II. Injector Module

A cross-section of the 120-kV, 8- x 10-cm injector module is shown in Fig. 2. The ions are produced in

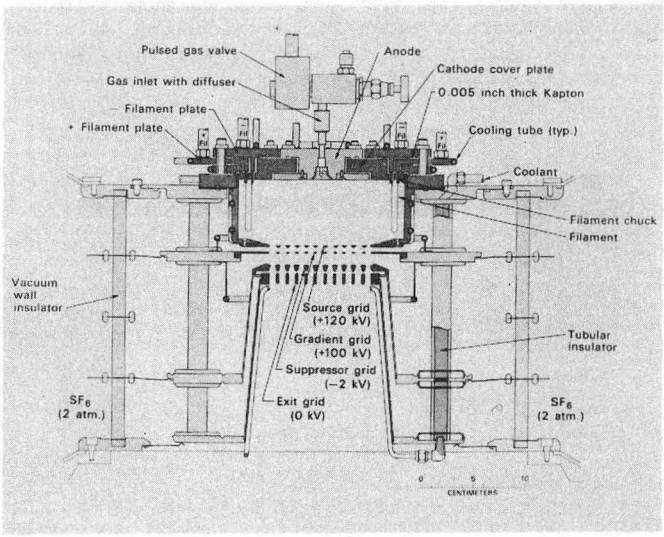

Figure 2. Cross-section of the 120-kV, 0.5-sec source module with an 8- x 10-cm grid array.

*Work performed under the auspices of the United States Department of Energy.

a high-current low-voltage discharge with no externally applied magnetic fields. The cathode consists of eighty-four 0.5-mm-diam, 11-cm-long tungsten filaments; the anode is a 10- x 10-cm molybdenum plate shown in the top of the figure. A photograph of the plasma source is shown in Fig. 3; details on this type of plasma generator can be found in Ref. 2.

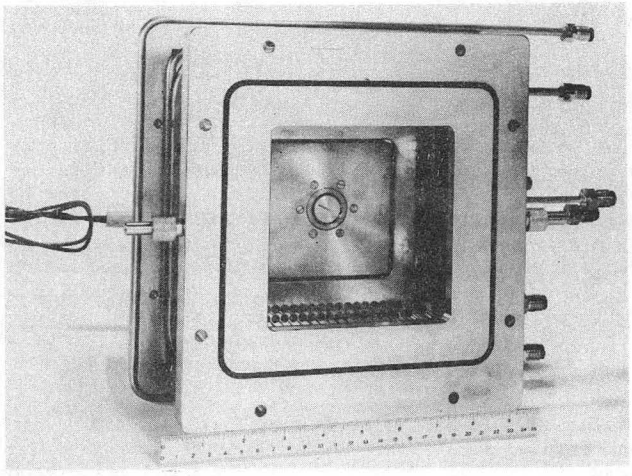

Figure 3. Photograph of the plasma source, illustrating the filament geometry. The flange with the O-ring was used for plasma-uniformity tests; it is not part of the structure shown in Figure 2.

A four-grid (three-gap) multiple-slot accelerator array (a cross section of a single slot of the array is shown in Fig. 4) is used. Ions are accelerated and electrostatically focused in the first two gaps; the third gap has a weak decelerating field to suppress down-stream electrons. The transparency of the array is 60%; the scale size was set by the desire to limit the maximum potential gradient to about 100 kV/cm (our estimate of the breakdown limit) and resulted in a design ion-current density of 0.31 A/cm^2 for a pure D^+ beam, or about 0.25 A/cm^2 for a beam with a realistic mixture of D^+, D_2^+, and D_3^+. The design shown in Fig. 4 was optimized, using the WOLF code,[9] by varying the shape of the first, beam-forming, electrode and the potential of the second, gradient-grid, electrode. The shapes of all electrodes except the first were chosen to minimize energy deposition in the structure by secondary particles created by ionization of the background gas or by secondary emission from grid surfaces.

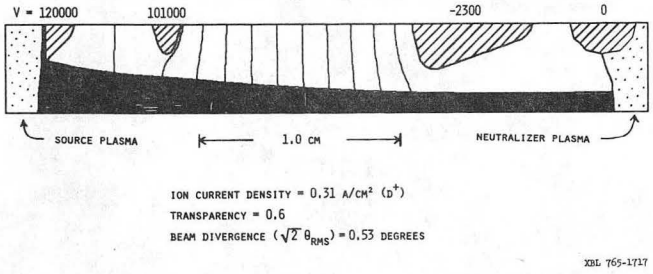

Figure 4. Calculated beam trajectories and equipotentials for a 120-kV accelerator.

The module (Fig. 2) consists of an outer, vacuum-wall insulator that is sectioned to distribute the potential gradients; to keep these insulators reasonably short, the outside of this insulator is pressurized with two atmospheres (absolute) of SF_6 gas. The plasma source and grid assembly are mounted on an inner plug-in structure (Fig. 5). The tubular insulators to which the grid assemblies are mounted also carry de-ionized cooling water to the plates that support the final three grid arrays; cooling for the first (beam-forming) grid is obtained from the plasma-source chamber. The 8-cm long grid rails, arranged in a 10-cm-wide array, are end cooled. The solid molybdenum rails are brazed to a fixed support on one end, forming a comb-shaped structure, and allowed to expand in the long direction to prevent buckling when heated.[7,8] The heat is conducted away in the 1-minute interval between pulses.

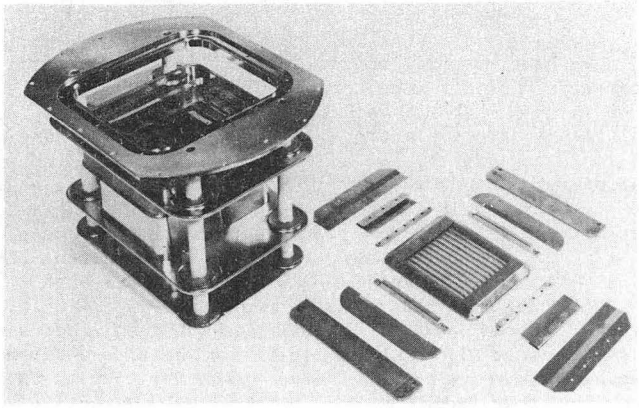

Figure 5. Photograph of the accelerator plug-in structure and one of four multi-slot grids.

The neutralizer to which this structure is attached is constructed of iron to shield the beam from stray magnetic fields. It has an internal cross section of 20 cm x 30 cm and is two meters long. D_2 gas emerging from the plasma generator through the grids produces a line density of $\sim 10^{16}$ molecules/cm^2 ($\sim$0.5 Pa-m) in this section.

The beam is stopped by a copper-plate calorimeter, instrumented with an array of thermistors, located 8.5 m from the grids. The beam divergence is determined from the shape of the heat pattern on the calorimeter[5]; the plate is water cooled in the 1-minute interval between shots.

A deflection magnet, located between the neutralizer and the calorimeter, can be used to sweep the ions out of the beam. An instrumented ion dump, similar to the calorimeter, is used to determine the focusing effects of the magnet (and possibly space charge) on the ions.

III. System Performance

Two structures of type shown in Fig. 2 have been operated up to 120 kV with 0.5-sec pulses. In the first (Mark I) the rails of the first two grids, beam-forming and gradient-grid, were curved to an 8.5-m radius to focus the beam in the direction parallel to the slots. The second structure (Mark II) had planar grid arrays.

A typical beam-pulse sequence is as follows: The water to the calorimeter is turned off and the diagnostic computer receives a signal to record the pre-shot thermistor temperatures on the calorimeter. Approximately 5 sec later the filament-power supply is turned on; approximately 2 sec later the filaments have reached their emission temperature and gas is pulsed into the plasma chamber. Within 20 msec the arc-power supply is turned on. When the discharge has stabilized ($\sim$50 msec after the supply has been turned on) the accelerator voltage is applied to the grids by firing the series switch.[3,4] The potential for the gradient grid is obtained from the accelerator power supply by means of a resistive voltage divider; the suppressor supply is slaved to the accelerator supply in that it is gated on by a signal from the high-voltage divider. The rise time of the

potentials applied to the three grids is approximately 30 μsec. When any of a number of fault sensors is activated (drop in high voltage below a preset threshold, loss of voltage across the first gap, excessive suppressor current, excessive gradient-grid current, etc.) the series switch is "opened" by firing the shunt switch.[3,4] This removes all high voltage from the grids; the discharge, however, is not turned off. After a preset "interrupt" time, typically 21 msec, the series switch is again fired and the sequence is repeated. At the end of the 0.5-sec pulse all power supplies are turned off. Approximately 5 sec later the final temperatures of the calorimeter thermistor array are recorded by the computer, and the calorimeter water is turned on to cool the plates.

A saturable-core reactor[3,4] dissipates much of the energy stored in the stray capacitance of the power supplies and cables; the stored energy delivered to the grids by a spark is approximately 2 J (the energy stored in the capacitance of the module). We have tried to determine the maximum stored energy allowed without adversely affecting operation of the module by adding capacitance to the source. Very preliminary results indicate that source performance is degraded when more than 7 J are dissipated in a spark.

Operation of the module by interrupting only the grid voltages and leaving the discharge on permits rapid re-starts. It does, however, cause a problem when the potentials are applied to the grids: Without any potential difference between the grids, ions and electrons from the discharge fill the grid region; when the potentials are applied, these ions and electrons must be swept out of the gaps (possibly emitting secondary electrons as they strike the grids) resulting in large currents from the power supply. If the power supply is not capable of providing the extra current this can load down the supply and prevent the required potentials from being applied to the grids -- which in turn gives rise to large currents, and so on. We have found that we can minimize this effect by "step-starting" the discharge: An RC circuit, with a time-constant of about 20 μsec, in series with a thyristor, is connected in parallel with the discharge; when the high-voltage series switch is fired, this thyristor is also fired to shunt the discharge current until the capacitor is charged. Because of the rapid deionization time (sub μsec) of the discharge, this puts a corresponding dip in the plasma density and thus decreases the ion and electron density in the grid region, minimizing the current surge when the voltages are applied to the grids. The recovery time of the plasma density in the discharge is comparable to the RC time of the circuit.

Typical operating parameters for both the Mark I and Mark II structures are given in Table I. The quoted beam widths, $\parallel$ and $\perp$ to the slots of the accelerator grid, were obtained from the temperature profile of the calorimeter located 8.5 m from the grids. The temperature profile was found to be bi-gaussian, i.e. of the form $A\exp-(x/x_o)^2 \exp-(y/y_o)^2$, so that it is possible to characterize the beam width by two parameters, x_o and y_o; we express these parameters as angles with respect to a point source located at the center of the grid array (no correction is made for the finite size of the source). Since the 8.5-m-radius grids of the Mark I structures focus the beam (in the direction parallel to the slots) at 8.5m, the parallel beam width of the Mark I structure is narrower than that of the Mark II (flat-grid) source.

The parameters given in Table I are for beams tuned for minimum divergence by adjusting the plasma density for a fixed set of grid potentials. The perpendicular beam width, as well as the gradient-grid and suppressor currents, increase drastically if the plasma density deviates from the optimum value by more than ± 10%.

Operation with deuterium was limited because of the large neutron fluxes produced by d-d reactions between the energetic deuterium ions of the beam and deuterium atoms buried in the copper calorimeter. The reaction rate built up gradually as the copper was loaded with deuterium from successive beam pulses. After approximately one-hundred 120-keV beam pulses the neutron-production rate reached an asymptotic value -- approximately 10^{11} neutrons/sec during a beam pulse.

Topics such as reliability, grid heating, molecular-ion composition of the beam, and improvements in beam optics are being investigated.

TABLE I. 120-kV 0.5-SEC PERFORMANCE CHARACTERISTICS OF TWO TEST MODULES WITH 8-CM x 10-CM ACCELERATOR-GRID ARRAYS. THE PARAMETERS LISTED ARE FOR BEAMS TUNED FOR MINIMUM DIVERGENCE (SEE TEXT).

	MARK I	MARK I	MARK II
GAS	H_2	D_2	H_2
GAS FLOW (T-ℓ/SEC)	4	7	7
ACCELERATOR CURRENT (A)	13	10	14
GAP 1 VOLTAGE (kV)	23	23	19
GRADIENT-GRID CURRENT, ELECTRONS TO GRID (mA)	10	10	40
SUPPRESSOR VOLTAGE (kV)	2.8	2.8	2.3
SUPPRESSOR CURRENT (A)	1.0	0.9	1.2
1/e BEAM WIDTH[a] MEASURED AT 8.5 M:			
$\perp$ TO SLOTS	±1.34°	±1.28°	±1.24°
$\parallel$ TO SLOTS	±0.42°	±0.42°	±0.76°
ARC POWER (kW)	25	19	23
FILAMENT POWER (kW)	18	18	18

[a] SEE TEXT

References

1. J. M. Haughian et al., Proc. Sixth Symp. on Engineering Problems of Fusion Research, San Diego, Ca., 1975, (IEEE Nuclear and Plasma Science Society, 1975), p. 53.
2. K. W. Ehlers et al., Proc. 9th Symp. on Fusion Technology, Garmisch, Germany, 1976, (Pergamon Press Oxford, 1976), p. 795.
3. D. B. Hopkins et al., Proc. 9th Symp. on Fusion Technology, Garmisch, Germany, 1976, (Pergamon Press, Oxford and New York, 1976), p. 897.
4. H. M. Owren, W. R. Baker, D. B. Hopkins, and R. C. Acker, "The Lawrence Berkeley Laboratory Power Supply System for Neutral Beam Source Development," paper presented at this conference.
5. C. F. Burrell et al., "Calorimetric and Optical Beam Diagnostics on the LBL 120-keV Neutral Beam Test Facility," paper presented at this conference.
6. K. W. Ehlers, "Rectangularly Shaped Large Area Plasma Source," paper presented at this conference.
7. J. A. Paterson et al., "The Design and Fabrication of an Ion Accelerator for TFTR-Type Neutral Beam Systems," paper presented at this conference.
8. L. A. Biagi and J. A. Paterson, "On Fabrication and Brazing of 120-kV, 65-A, 0.5-Sec Accelerator Grid Assemblies," paper presented at this conference.
9. W. S. Cooper, K. Halbach, and S. B. Magyary, Proc. of the Second Symposium on Ion Sources and the Formation of Ion Beams, Berkeley, CA, 1974, p. II-1; LBL-3317.

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LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720