Title

STATUS OF THE DEVELOPMENT OF A 120kV NEUTRAL BEAM INJECTOR SYSTEM FOR THE TFTR TOKAMAK

Author

Berkner, K.H.

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K. H. Berkner, W. R. Baker, F. Burrell, W. S. Cooper,
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DISCLAIMER

Status of the Development of a 120 kV Neutral Beam Injector System for the TFTR Tokamak*

K. H. Berkner, W. R. Baker, F. Burrell, W. S. Cooper, K. W. Ehlers, W. B. Kunkel
D. Massoletti, H. M. Owren, R. V. Pyle and J. W. Stearns

Lawrence Berkeley Laboratory, University of California
Berkeley, California 94720

Abstract

The plasma in the TFTR Tokamak at the Princeton Plasma Physics Laboratory will be heated by four neutral beam injection systems (12 sources) providing 0.5-sec pulses of 19 MW (total) of 120 keV D^0 atoms, plus 6 MW of 80- and 40-keV D^0 atoms. Based on a conceptual design prepared three years ago, we began the development of suitable components and systems, including plasma sources, accelerators, neutralizers, magnets, beam dumps, electronics, diagnostics, and controls. We have recently tested the developmental components of such a system, including an 120 kV, 65A ion source to full voltage and current. A prototype TFTR injection system is under construction at LBL by the Engineering and Technical Services Division and will start operating at the end of this year.

I. Introduction

In 1975 the Neutral Beam Staff of the Lawrence Laboratories prepared a conceptual design of a Neutral Beam Injection System for the TFTR Tokamak at the Princeton Plasma Physics Laboratory [1]. The design called for four beam lines, each equipped with three sources, to inject a total 19 MW of 120-keV D^0 atoms in 0.5-sec pulses (plus 6 MW of 80- and 40-keV D^0 atoms) at 5 minute intervals. At that time there were no operational large-current 120-keV ion sources.

Early in 1976 the Lawrence Laboratories were commissioned to build and test a prototype TFTR beam line. The detailed design and fabrication of a beam line, and a power supply to test one source on the beamline, were assigned to the LBL Engineering and Technical Services Division, augmented by engineers from LLL. The development of the injectors came under the auspices of the Neutral Beam Development Group in the LBL Accelerator and Fusion Research Division. The prototype injection system will start operating at the end of 1978. The development of the injectors and some of the components is described in this paper.

II. Injector Module

The design concepts for the injector (plasma source/accelerator) were tested on a fractional area source which has been described previously [2]. This injector, operated at 120 kV, produced ∿14A of hydrogen ions or ∿10A of deuterium ions in 0.5-sec pulses. The beam profile at 8.5 m was bi-gaussian with 1/e half-widths of approximately $1.3^o \times 0.4^o$ [2]. Recently work has started on operating this small-scale injector at longer pulse lengths. To date the longest high-power pulse length is 1.5 sec, 10A, at 110 keV.

A cross-section of the full-scale TFTR injector module is shown in Fig. 1. The plasma source (upper section of Fig. 1) is a high-current, low-voltage discharge with no externally applied magnetic fields. A photograph of the plasma source, viewed from the accelerator grids, is shown in Fig. 2. The cathode consists of 204 hairpin filaments, 0.5-mm diam and 11-cm long, distributed along the top and bottom of the rectangular chamber. The anode consists of the three smaller rectangles seen in the figure at the rear of the chamber.

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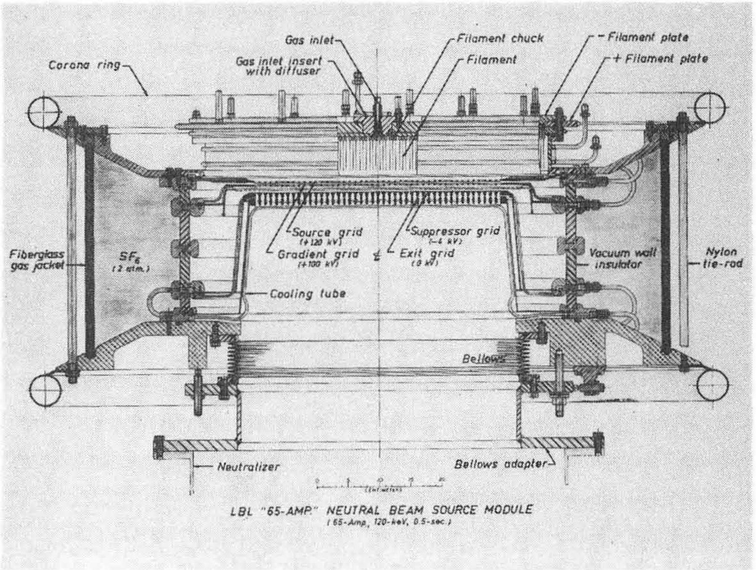

Figure 1: Cross section of the 120-kV, 65-A, 0.5-sec TFTR injector module.

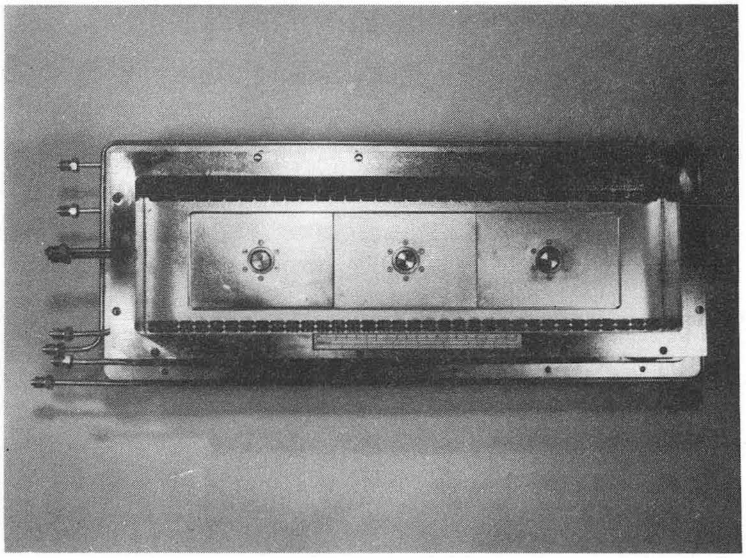

Figure 2: Photograph of the plasma source, viewed from the accelerator grids.

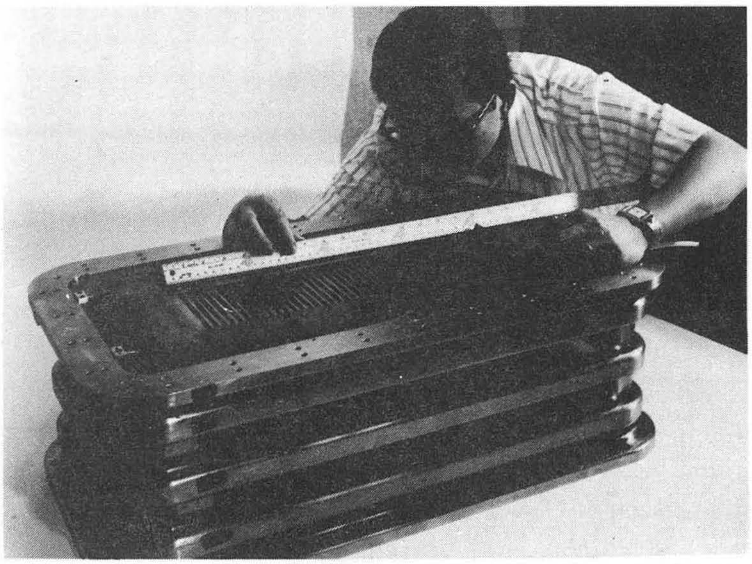

Figure 3: Photograph of the accelerator.

Gas is introduced through the circular apertures in each of the anodes. The operational characteristics of the plasma source have been described earlier [3].

The accelerator, shown in Fig. 3, consists of four electrodes separated by epoxy insulators which form the vacuum wall. This structure is surrounded by a fiberglass jacket (not shown in Fig. 3) which is pressurized with 2 atmospheres (200,000 Pa) of SF_6 gas to facilitate voltage holdoff across the relatively short epoxy insulators. The 10- x 40-cm, 60% transparent, multiple-slot accelerator-grid array, consists of 4 layers of shaped, molybdenum bars which are identical to those of the 8- x 10-cm array described in [2]. The bars are end cooled by water flowing through their support frame. Design and fabrication details have been reported in [4] and [5].

The operational tests of this module have been limited to short pulses by the availability of suitable power supplies. The LBL Test Stand IIIB has a thyristor-switched, capacitor-bank power supply [6] which limits pulse lengths, at full current, to about 15 msec. Tests up to the 0.5-sec design pulse lengths of the TFTR module will be carried out on the Lawrence Livermore Laboratory High Voltage Test Stand (HVTS) in the near future. Since the design is similar to that of the 8- x 10-cm module that has been operated routinely with 0.5-sec pulses, no great problems are anticipated.

The TFTR module, installed on TS IIIB is shown in Fig. 4. The large circular flange is the base of the SF_6 shroud which was removed to reveal the plasma source and accelerator.

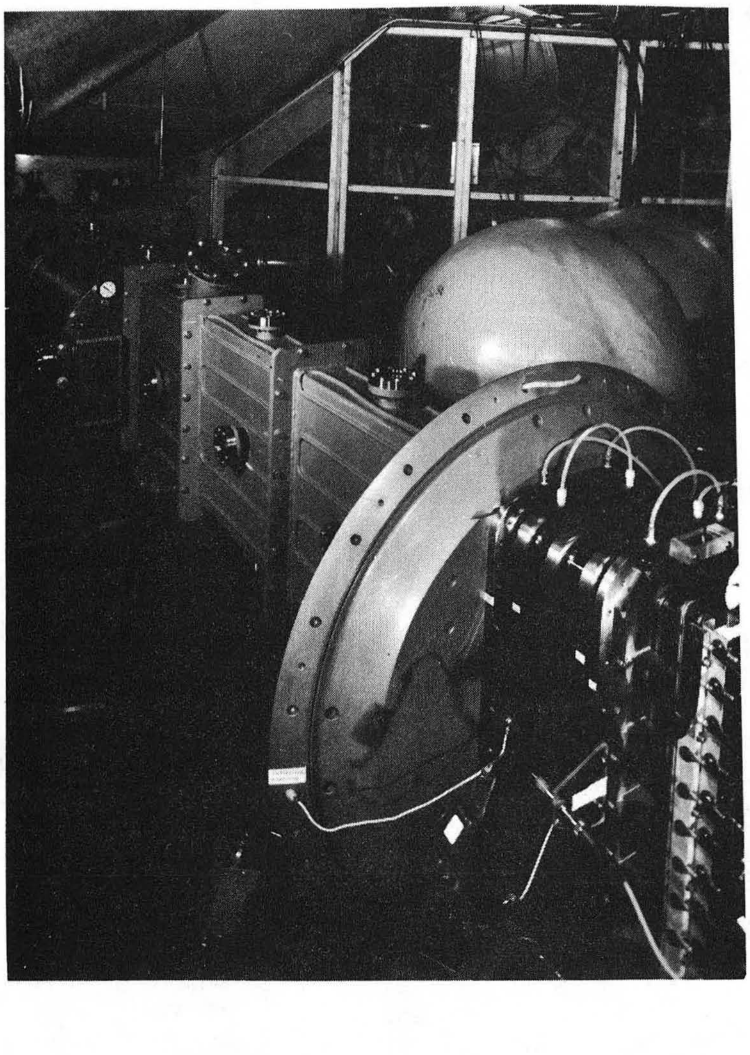

Figure 4: TFTR module installed on TS IIIB.

The rectangular portion of the beam line is the 15-cm x 50-cm x 2-m neutralizer section; the viewing ports are for Doppler-shift-spectroscopy analysis of the beam. The two domes in the background contain the arc and filament power supplies. Sample operating characteristics for 120-kV deuterium and hydrogen beams are given in Table I.

Table I

Sample Operating Characteristics of the TFTR Module for 120 kV deuterium and hydrogen beams.

	gas flow	I_{accel}	gradient grid		suppressor		arc	
			V	I	V	I	V	I
D_2	15 T-ℓ/sec	67A	98 kV	200 mA	-2 kV	11A	53V	2300A
H_2	28 T-ℓ/sec	94A	96 kV	220 mA	-2 kV	12.5A	59V	2200A

The suppressor- and gradient-grid currents increase with increasing gas flow, indicating they arise from ionization of gas in the grid region.

Only preliminary results on species and beam divergence are available at this time. For deuterium operation the accelerated ions are approximately 70% D^+, 20% D_2^+, and 10% D_3^+. The beam can be characterized by a bigaussian source uniformly distributed over a 10-cm x 40-cm area at the source with 1/e half-widths of approximately $1.1^o \times 0.4^o$. This is better than the $1.3^o \times 0.4^o$ observed for the smaller source. At this time it is not clear whether this apparent improvement is real or whether it is instrumental.

III. Diagnostics and Controls

The test facilities are used not only for the development of injectors, but also for the development of diagnostic techniques, controls, and power supply-components. The latter is discussed in [6] at this conference.

The standard diagnostic tool for determining the beam profile is a thermistor array inbedded in our thermal-inertia beam dumps: 2-cm thick copper plates in a V-shape configuration to limit the peak power density (Fig. 5). The thermistor readings are recorded by a computer prior to the beam pulse and after the beam pulse to determine the thermal imprint of the beam. The plates are cooled between beam pulses, during which time the computer is used to fit the thermal pattern to a bi-gaussian distribution which characterizes the beam.

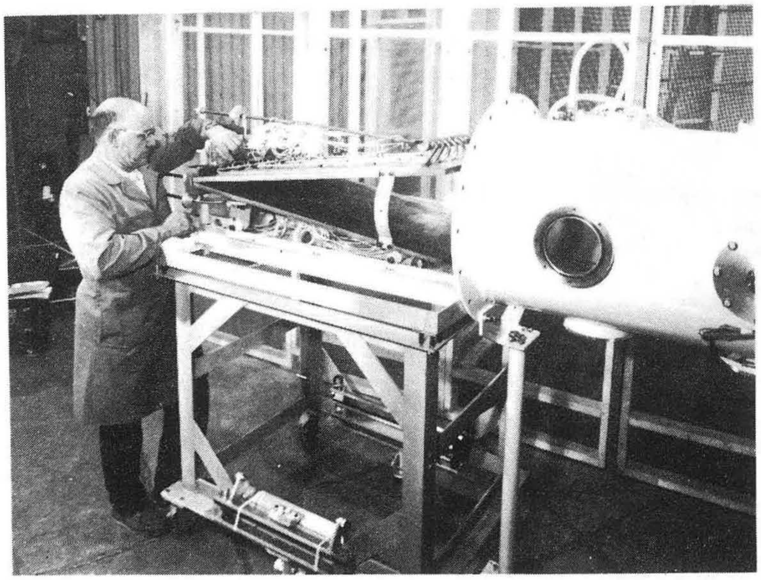

Figure 5: Thermal-inertia beam dump

The power deposited to the calorimeter is determined either from the thermistor temperatures or by water-flow calorimetry. We have recently found that the epoxy used to bond the thermistors to the copper plates deteriorates after repeated thermal cycling in vacuum, resulting in a poor thermal joint. We are investigating other bonding techniques.

Another diagnostic technique that has proven to be extremely useful is Doppler-shift spectroscopy of the light emitted by the atoms in the beam [7]. An optical spectrometer equipped with a 500-channel vidicon is used to analyze the beam divergence of all energy components in the neutral beam, the relative population of full-, half-, and third-energy components, and the aiming direction of the beams.

One of the test facilities has been equipped with a computer control system in a collaborative effort with the Charles Stark Draper Laboratory. This system provides for controlling all power supplies and includes a conditioning algorithm for bringing a new accelerator structure up to operating voltage. The system can be used to obtain tuning curves of beam divergence versus beam current. The system has worked successfully although it is still being developed and has had limited testing.

The improvement of these and other techniques, as well as reliability of operation, grid heat loads, molecular-ion composition, and beam optics are continuing topics of investigation.

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TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720