CONF-820948--14

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DE84 004460

DEVELOPMENT OF AN ION SOURCE FOR LONG-PULSE (30-s) NEUTRAL BEAM INJECTION*

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ABSTRACT

This paper describes the development of a long-pulse positive ion source that has been designed to provide high brightness deuterium beams (divergence ≅ 0.25° rms, current density ≅ 0.15 $A \cdot cm^{-2}$) of 40-45 A, at a beam energy of 80 keV, for pulse lengths up to 30 s. The design and construction of the ion source components are described with particular emphasis placed on the long-pulse cathode assembly and ion accelerator.

1. INTRODUCTION

The technique of neutral beam injection has established its efficacy in heating the plasma in a wide range of magnetic confinement fusion devices /1/. All the neutral injection experiments to date have been conducted using subsecond pulse lengths (20-500 ms). The technology of producing multimegawatt neutral beams is now entering a new regime characterized by a pulse duration extending to several seconds. This paper describes the development of a long-pulse positive ion source aimed at the neutral injection requirements for the MFTF-B experiment at the Lawrence Livermore National Laboratory. Although this experiment involves the use of a variety of neutral beam injectors, certain applications like the axicell and the anchor beams demand about 25 A of 80-keV D^0 of 30-s pulse duration to a plasma target of approximately ±0.8° × ±1.9°. The ion source under discussion is designed to provide the technological data base required for the fabrication of such long-pulse injectors. In what follows we shall describe the special features of the long-pulse plasma generator and the accelerator.

2. THE PLASMA GENERATOR

The Oak Ridge National Laboratory (ORNL) duoPIGatron-type plasma generator /2/ that was employed in the PLT, ISX, and PDX neutral beam injectors utilized oxide-coated filaments as the electron emitter. In the case of the PDX injector /3/, 12 such filaments, each carrying 40 A of heating current, were able to provide intense arc discharges (150 V/1200 A) as long as the pulse duration was kept small (<500 ms). Since the arc current completes through the filament and the filament heating current constitutes only about 40% of the full arc current, it was not possible to increase the discharge duration much beyond the thermal time constant of the oxide filaments. The development of alternate cathodes with high emission current density (≅10 $A \cdot cm^{-2}$) was crucial to extending the discharge duration to multisecond levels. Hollow cathodes /4/ were tested and offered moderate success /5/. Emitting surfaces made of lanthanum-oxide-doped molybdenum were found to be more stable compared with LaB_6 although the current density for the former was lower. Subsequent investigations using

*Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

indirectly heated cathodes, where the emitting shell was heated by graphite heaters, were quite encouraging. Such cathodes were tested in several geometries /6/, and the most promising configuration is shown in fig. 1.

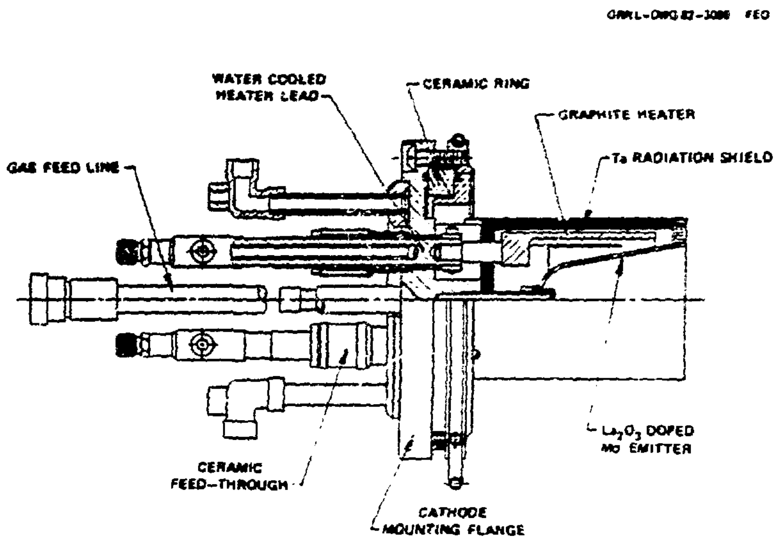

Fig. 1. The cathode configuration.

The basic cathode structure has an emission area of about 100 cm^2 on the inside surface of a paraboloid of about 5-cm diameter at the open end. The emitting shell was made by plasma spraying a mixture of 97.5% Mo, 2.0% La_2O_3, and 0.5% Pt by weight onto an aluminum mandrel to a thickness of about 1.5 mm. Details of the fabrication and heat treatment of the cathode are described by Schechter and Tsai /6/. The heater requirement for each cathode is about 3 kW (9 V/360 A), and the corresponding emitter temperature was measured to be about 1900 K. These cathodes were operated at emission levels of 12 $A \cdot cm^{-2}$ for subsecond (100–200-ms) pulses. As shown in fig. 2, two of these cathodes were utilized in a plasma generator with a 28- × 60-cm anode chamber cross section and 40-cm length to obtain 120-V/1200-A arc discharges of 35-s pulse duration (fig. 3). The plasma uniformity profile corresponding

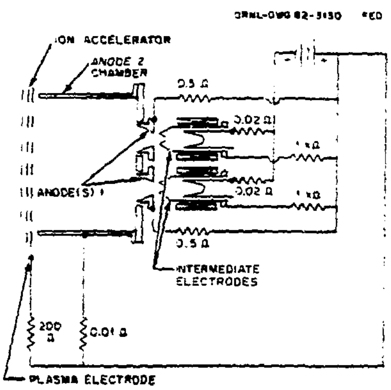

Fig. 2. Schematic of the source operation.

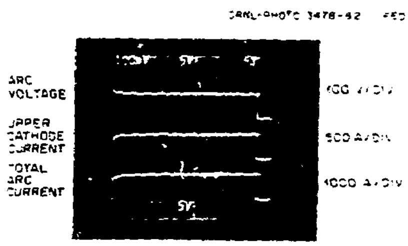

Fig. 3. 120-V/1200-A arc of 35-s duration.

to the above arc levels, measured under short-pulse (100-ms) conditions, is shown in fig. 4. The cathode was evaluated using an accelerated test procedure. With two cathodes providing an arc discharge of 110 V/1100 A, 1778 pulses of 4.5-s pulse width were produced at high duty cycle (22%) with 91.3% reliability. After this, one of the cathodes was disconnected and the arc current with a single cathode was increased to 760 A while the pulse length was increased to 30 s. The operation failed after 18 such pulses at high duty cycle (25%), but the failure was subsequently identified with inadequate cooling of the intermediate electrode. The basic cathode structure showed no degradation. In this experiment the graphite heater was connected to the copper heater leads through a tantalum rod. There was some deterioration of the tantalum-graphite junction; this problem was corrected in the version shown in fig. 1 by extending the graphite to the water-cooled copper leads.

Figure 5 shows the long-pulse ion source. With regard to long-pulse operation the remaining modifications that have been incorporated into the plasma generator were mainly to provide improved cooling. The heat loading due to the arc discharge on different components of the plasma generator was experimentally determined using a scaled-down version of the ion source (25- x 35-cm arc chamber). The results are shown in Table I.

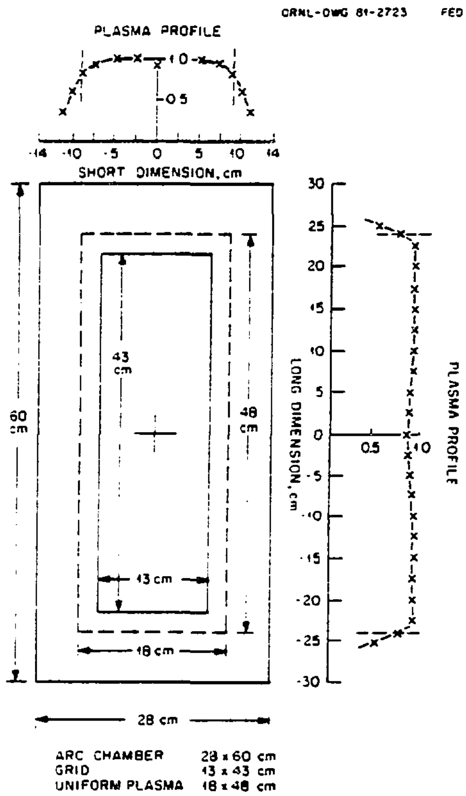

Fig. 4. Plasma density profiles at the extraction plane.

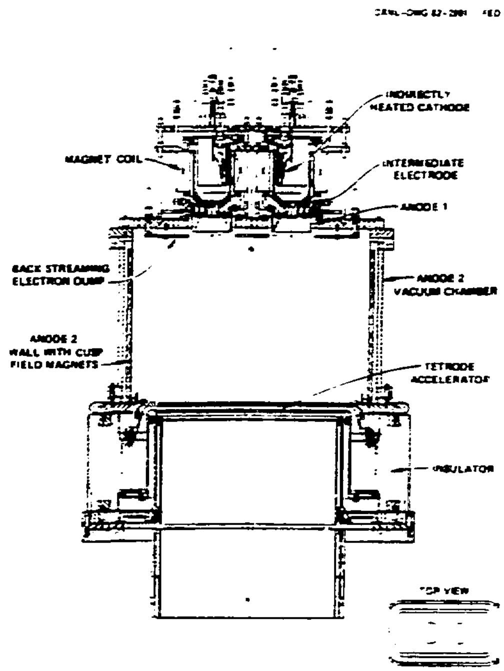

Fig. 5. The long-pulse ion source.

Table I. Power Loading on Source Components Due to Arc Operation.

Source component	Arc power loading (%)
I.E. snout region	26
I.E. liner + filament flange	16
Anode 1	12
Anode 2 back wall	5
Anode 2 side wall	23
Plasma grid	12
Other parts	6

An appreciable portion of the arc power is dissipated at the mouth of the intermediate electrode chamber. Improved cooling of the intermediate electrode parts was provided by electroforming a large number of cooling channels onto these parts. Measurements of back-streaming electron loading /7/ show that about 3% of the accelerator drain power is dissipated in the arc chamber, with about 60% appearing on the back plate of the arc chamber. This plate is therefore made with electroformed cooling channels. Similar cooling channels were also provided on the second anode wall on which the cusp field magnets are mounted. Unlike the previous designs from Oak Ridge /2,3/, this wall does not form a vacuum wall and hence is made thinner, thereby increasing the cusp magnetic field strength at the inner wall surface.

3. ACCELERATOR

Utilizing the two-dimensional (2-D) ion extraction code developed at ORNL /8/, a two-stage ion accelerator has been designed to provide an aberration-limited beamlet divergence of 0.25° rms angle at a current density (D^+) of 0.15 $A \cdot cm^{-2}$. The aperture shapes are illustrated in fig. 6 together with the primary ion trajectories. The apertures on the plasma grid have an 8-mm I.D. The ground electrode is relatively thick (10 mm), which increases the absorption of the neutralizer plasma on the aperture walls /9/. This, in turn, reduces the ion current extracted from the neutralizer plasma by the decel voltage, thereby minimizing the secondary electron production at the suppressor grid. Significant reduction in the heat loading on the grids is expected.

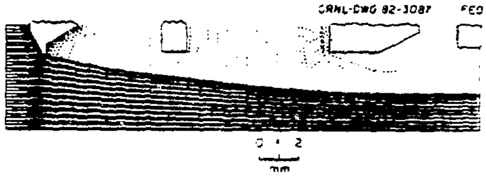

Fig. 6. Aperture geometry of the accelerator.

New techniques have been adopted in the fabrication of an accelerator that improves the cooling efficiency while maximizing the grid transparency. Copper electrodes with a 13- × 43-cm active grid pattern and with serpentine cooling passages around each aperture have been fabricated using an electroforming technique. The large aperture size and the wavy cooling channels provide high grid transparency (48%) and efficient cooling of the electrodes. The fabrication procedure consisted of milling the cooling passages on a flat piece of OFHC copper, filling the channels with wax, silvering the wax surface, electrodepositing a thin (≈1-mm) layer of copper, removing the wax, machining the coated surface flat, testing the coating quality in a furnace, machining the apertures, cutting the grid to its final dimensions, brazing the water manifold and the grid mounting frame, and finally curving the grid to generate the required focal length. A completed plasma grid is shown in fig. 7.

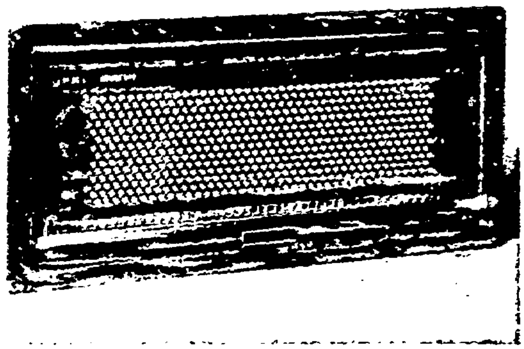

Fig. 7. A completed plasma grid.

4. STATUS OF THE ION SOURCE TEST

All the parts of the ion source have been fabricated and the ion source assembly has been completed. The test facility that was used for the development of the PDX injectors has been modified for long-pulse operation. A modulator system, capable of providing 80 kV/60 A for long pulse lengths, has been installed and is undergoing final checkout. After establishing satisfactory operation of this modulator system, testing of the long-pulse ion source will be carried out.

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