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DC PLASMA GENERATOR DEVELOPMENT FOR NEUTRAL-BEAM INJECTORS*

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ABSTRACT

Rectangular plasma generators are being developed with the capability of producing hydrogen ion beams of 60-100 A. Using single and double electron feed configurations of the duoPIGatron type, these generators have been operated at arc levels of 1200 A for pulse lengths of >30 s. The plasma density and uniformity are sufficient for extracting ∿60-A hydrogen ions using a 13 × 43 cm accelerator and ∿100 A with an 18 × 48 cm accelerator.

INTRODUCTION

Intense neutral beam injection is a viable plasma heating technique. High power neutral beam injectors based on the advanced positive ion systems could be used for heating experiments on a reactor-grade plasma.[1,2] The ion sources for such applications have a development goal of operating at a beam energy of 100-200 keV, hydrogen or deuterium ion currents of ∿100 A, and pulse lengths of many seconds extending to dc. The plasma generator should be developed with dc capability and

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characteristics such as those listed in Table 1. The fast and smooth turnon of the arc discharge and the production of a uniform plasma are essential for reliable ion source operation. The high arc efficiency will aid significantly to the development of a long pulse electron emitter. High gas efficiency will reduce energy straggling in an accelerator and improve atomic fraction in the ion beams formed.[3] High atomic yield is essential to improve plasma core heating and to minimize plasma edge heating.

PLASMA GENERATOR DEVELOPMENT

Recently, the technology of neutral beam systems including several types of ion sources has been reviewed by Menon.[4] One of the positive ion sources developed for neutral beam applications is the Oak Ridge National Laboratory (ORNL) duoPIGatron ion source, the development of which was begun by Morgan[5] at ORNL. As shown in Table 2, this type of ion source has undergone considerable development in the last decade. Ion sources with grid diameters ranging from 5 to 30 cm that produce hydrogen ion beams of 5-100 A and pulse lengths of 50-500 ms have been developed. Some of these ion sources are currently used in the neutral beam injectors for PLT,[6] ISX-B,[7] and PDX.[8] Utilizing the multiple line cusp magnetic field configuration for confining fast electrons and slow charged particles in the source plasma[9] has contributed to the fast progress in ion source technology. For producing long pulse ion beams, a rectangular ion accelerator has been designed with improvements in water cooling and mechanical stability. The development of the rectangular plasma generator to match the rectangular accelerator has been

Table 1. The plasma generators are aimed at the following characteristics

Excellent plasma properties	
High current density	∿0.4 A/cm^2
Uniform plasma	±5∿10%
High atomic yield	>80%
Good operating characteristics	
Smooth and rapid turnon	<10 ms
High arc efficiency	>1.5 T[a] A/kW
dc capability	>30 s
Long cathode lifetime	10^6 s potential

[a]Geometric transparency = ratio of grid extraction area to plasma area in which density variations are within ±10%.

Table 2. ORNL has developed duoPIGatron ion sources with circular and rectangular cross sections for neutral beam heating

Year	Grid size	Hydrogen beam current (A)	Pulse length	Application
1972-73	7-cm diameter	5	50 ms	ORMAK
1974	10-cm diameter	10	50 ms	ORMAK
1975	15-cm diameter[a]	30	100 ms	ORMAK, LITE
1976-77	22-cm diameter[a]	60	300 ms	PLT, ISX-B
1978-80	30-cm diameter[a]	100	500 ms	PDX, ISX-B
1979	10 × 25 cm[a]	25	∿5 s	R&D
1980	13 × 43 cm[a]	60	∿5 s	TFTR-U,[b] DIII-U[b]
1981	18 × 48 cm[a]	100	∿30 s	ISX-C,[b] MFTF-B[b]

[a]Multiple line cusp magnetic field has been successfully used for confining source plasma in ion sources for neutral beam injectors.

[b]Potentially applicable to them.

pursued since 1979. After briefly describing the operation of a modified duoPIGatron, the significant progress in the dc plasma generator development is elaborated and discussed in the following.

Figure 1 shows a schematic diagram of a modified duoPIGatron ion source. The plasma generator consists of an electron emitter, an intermediate electrode with a magnetic field coil, anode 1, anode 2, and a plasma grid (the first grid of the ion accelerator). Under normal operations, the electron emitter is heated to its operating temperature. For each pulsed arc discharge, the gas feed is turned on about 100 ms ahead of the arc voltage. During the turn-on transient, the primary electrons from the electron emitter ionize the hydrogen gas (∿100 mtorr) and produce a dense cathode plasma within the intermediate electrode. As in a conventional duoPIGatron,[10] the cathode plasma supplies fast electrons to create a dense anode plasma in the anode 1 region. The electron emitter, intermediate electrode, and anode 1 form an electron feed assembly.

The source magnetic field from the intermediate electrode only serves to guide the fast electrons through the electron feed assembly. On the other hand, the multiple line cusp magnetic field inside the anode 2 chamber serves to confine both the fast and slow electrons in the anode plasma. Normally, a strong source magnetic field is not needed. The magnetic flux at the plasma grid due to the source coil is usually below 5 G. Thus, the plasma uniformity in the extraction region is controlled by the multiple line cusp magnetic field. Under normal operations, a uniform plasma extending to within 5 cm of the arc chamber walls can readily be produced. The same feature is also found in a rectangular plasma generator.[11]

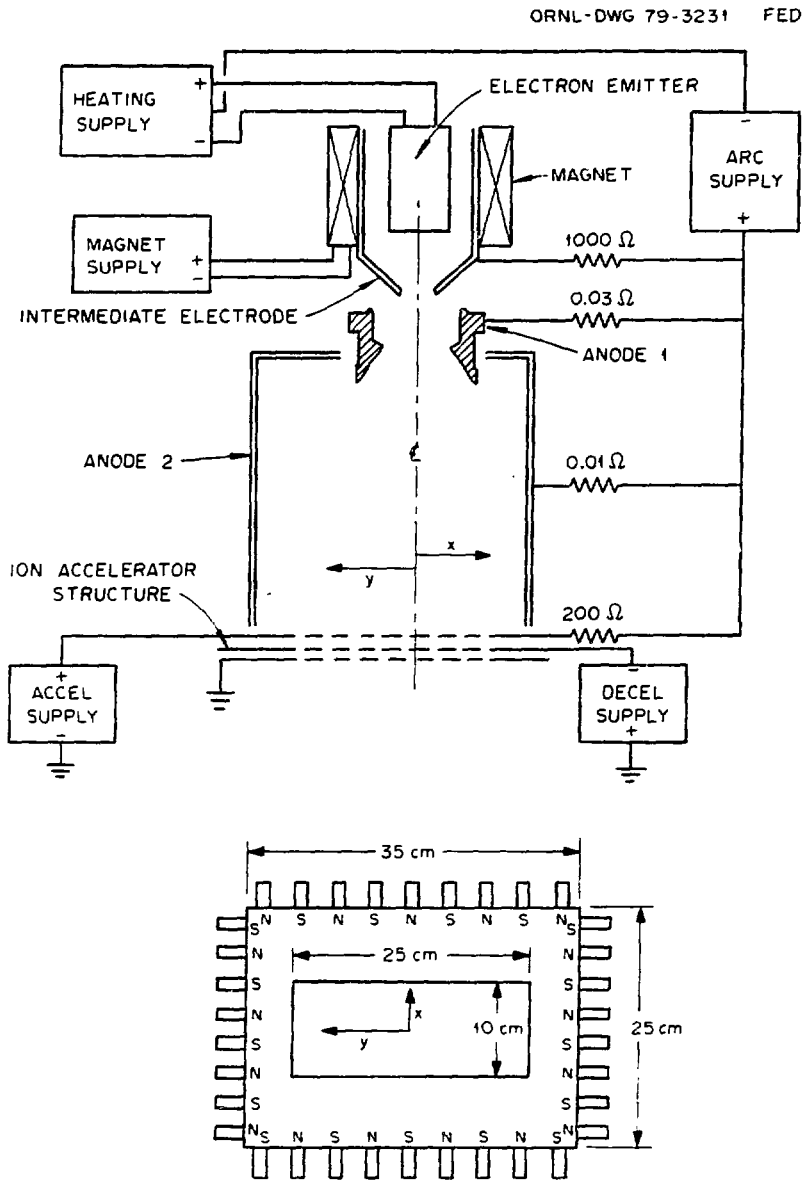

Fig. 1. Schematic diagram of a modified duoPIGatron ion source.

The anode plasma is created by fast electrons via electron-molecule ionization collision processes. Before reaching the plasma grid, the fast electrons dissipate most of their energy and produce insignificant amounts of molecular ions in the extraction region. On the other hand, the cold plasma electrons in the anode plasma dissociate molecular ions and enrich atomic ions.[12] Thus, the duoPIGatron ion sources are capable of producing ion beams with ∿80% of atomic fractions.[8] Energy straggling in an ion accelerator may lower the effective atomic ion yield of an ion source.[3]

Considering the capability to produce ion beams with high atomic fraction and the reliable operation of neutral beam injectors on PLT, ISX-B, and PDX, the duoPIGatron ion source is a prime candidate for reactor-grade neutral beam injector development. A rectangular plasma generator (Fig. 2) is being developed for producing hydrogen ion beams of 60-100 A and >30 s.

Assuming a beam current density of 0.25 A/cm^2 and 46% grid transparency, the grid size for a 100-A ion current is 18 × 48 cm. The arc chamber cross section is designed to be 28 × 60 cm. As shown in Fig. 2, the multiple line cusp magnetic confinement is employed to contain the anode plasma. The fast electrons for producing the anode plasma are provided either from single or double electron feed configurations. Figure 2 shows the schematic diagram of the plasma generator with a double electron feed. The typical plasma profiles are shown in Fig. 3. Usually, the plasma density increases linearly with the arc power. For both types of electron feeds, the arc power level has been pushed to about 180 kW (or >1200 A) for 30 s. Under such arc conditions, the

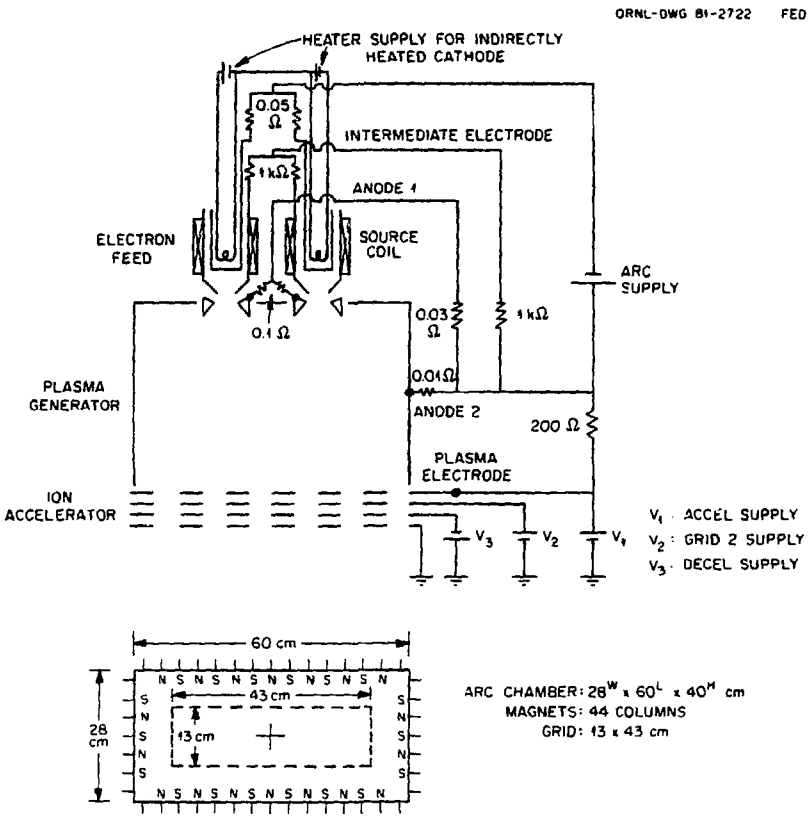

Fig. 2. Schematic diagram of a 60-100-A ion source.

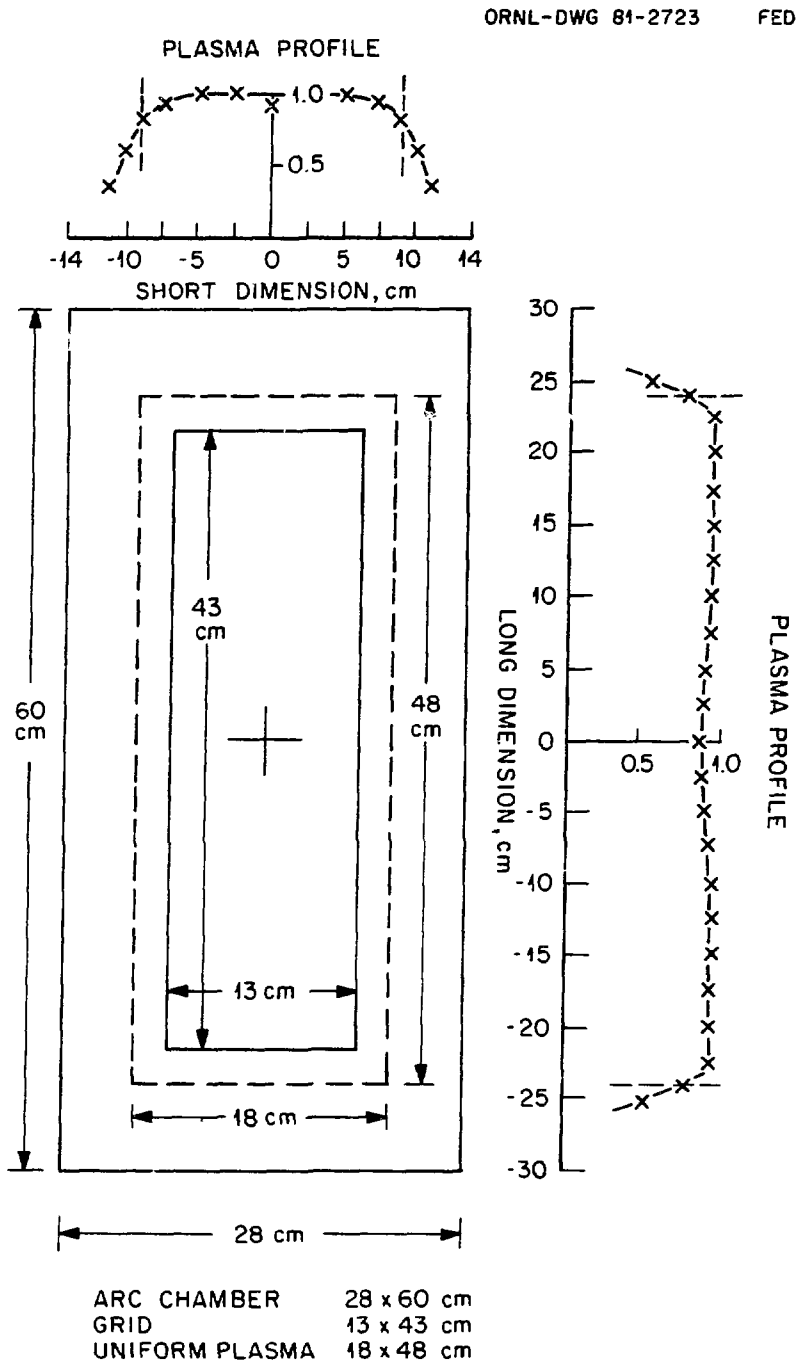

Fig. 3. Typical spatial uniformity of anode plasma in the extraction region.

plasma density and uniformity are sufficient for delivering ∿60-A hydrogen ions using a 13 × 43 cm accelerator and ∿100 A using an 18 by 48 cm accelerator.

The above significant result is made possible by the development of long pulse electron emitters, which are made of LM (Mo doped with La_2O_3) indirectly heated cathodes. The module current capabilities of 500 A and 1000 A are available. The details of the emitter development are described by Schechter.[13]

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