LBL-19568

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Accelerator & Fusion Research Division

LBL--19568

DE86 005499

Presented at the 11th Symposium on Fusion Engineering, Austin, TX, November 18-22, 1985

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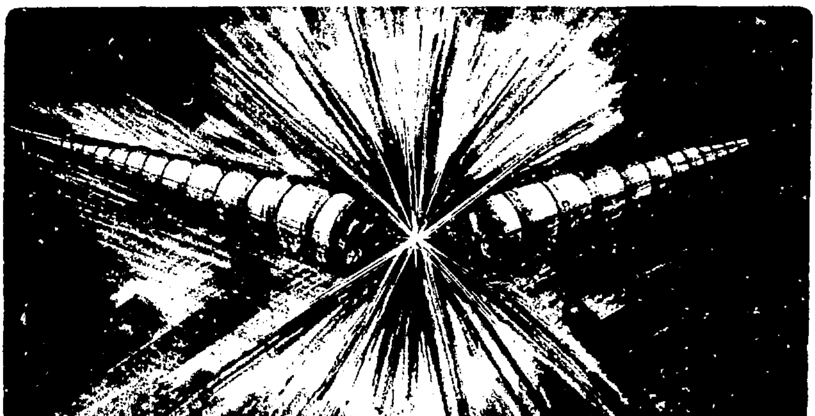
November 1985



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

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The U.S. positive ion neutral beam program has developed a single design, the Common Long Pulse Source (CLPS), which will provide multi-second beam heating for TFTR, MFTF-B and GA's Big D. Following competitive prototype testing, the LBL design was selected for industrialization because it could both meet the performance requirements of all three users, and fit within all space constraints. The LBL accelerator design is based on a slot type of aperture, with water cooled molybdenum grid tubes. The plasma generator is a magnetic bucket arc chamber, with multiple tungsten wire filaments. Beam test results are presented for the 10 x 40 cm prototype source with 80 kV and 120 kV gaps. The initial test results from the first 12 x 48 cm CLPS industrial plasma generator, made by RCA, are also presented.

Introduction

For the past decade, the positive ion based neutral beam programs in the U.S., Japan, and Europe have been the developing long pulse, water cooled sources.[1,2,3] Two general types of accelerator design have been used: holes; and slots. Accelerators with the hole type of aperture have a relatively simple mechanical design, and appear to be operable over a wider range of perveance. The hole type of aperture has been adopted for long pulse sources at JAERI for the JT-60 tokamak, at Culham for the JET tokamak. In the U.S., the group at Oak Ridge provided short pulse hole type sources for the PLT and PDX tokamaks.[4]

The slot aperture developed at LBL has a higher grid transparency than holes, but a more complex mechanical structure. For long pulse sources, the slot design delivers 40% to 60% more ion current from a given area extractor. The slot geometry is preferred for applications where maximum injected power is required from a limited access area. Short pulse slot type accelerators have been developed in the past for 2XII-B,[5] MFTF-B,[6] and Doublet-III,[7] and MFTF B.[8] An additional advantage of slots is that the molybdenum grid tubes provides a natural water cooling channel, and the molybdenum is much less susceptible to operations damage than copper.

The first prototype long pulse accelerator at LBL was a water cooled 10 x 10 cm tetrode, which was first tested with a field-free type of plasma generator.[1] The four accelerator electrodes were made of hollow molybdenum tubing, actively cooled with high pressure water. The grid tubes have a designed thermal response time of a few milliseconds, and an operating limit of 1200 Watts per 10 cm rail. A 10 x 40 cm prototype long pulse accelerator (LPA) was then built, and test results are reported here. The LPA was designed to operate at either 80 kV or 120 kV by shimming the gap between the second (gradient) and third (suppressor) grids.

Concurrently, magnetic bucket plasma generator development started with a 10 x 10 cm short pulse design, which was tested with the 10 x 10 cm prototype accelerator. A magnetic bucket design was required to meet MFTF-B requirements for 80% atomic fraction. A prototype 10 x 40 cm long pulse plasma source (LPS) was later constructed for testing with the LPA. The LPS is a magnetic bucket chamber with (34) 60 mil tungsten filaments. The bucket sidewalls and backplate are actively cooled to dissipate the backstreaming electron power from the accelerator. The filament sandwich is made of copper plates with gundrilled water cooling channels.

The 10 x 40 cm LPA/LPS ion source was first tested for MFTF B, 80 kV, 30 second deuterium operation. Subsequently, TFTR and GA developed long pulse beam requirements: 120 kV, 2 second deuterium for TFTR; and 80 kV, 5 second hydrogen for GA's Big-D. The pulse lengths are basically dictated by the users' existing inertial ion dumps, since the source is a dc design. The plasma generator is unchanged for 80 or 120 kV operation, but does require additional anode when switching from hydrogen to deuterium. The extra anode required for hydrogen is provided by connecting the prode plate to anode. The accelerator is unaffected by the change in gas, but must be gapped for either 80 or 120 kV.

The beam test results reported here are for the 10 x 40 cm LPS/LPA. The plasma properties of the LPS plasma generator have previously been reported.[9] Beam testing was carried out on the Neutral Beam Engineering Test Facility (NBETF) at LBL from March, 1983 to November, 1985. The test sequence was: (1) 80 kV, 30 second deuterium (MFTF-B); (2) 120 kV, 2 second deuterium (TFTR); and (3) 80/kV hydrogen (GA Big-D). Following the LBL 30 second testing, a long pulse hole aperture prototype developed at Oak Ridge was also tested on NBETF. The LBL design was selected as the baseline for the long pulse source for three reasons: (a) Demonstrated 80 kV 30 second *deuterium current*; *(b) Projected 120 kV deuterium* current; and (c) Development of a single source design which could meet all three user performance requirements and fit within the TFTR space envelope. The user CLPS performance requirements are summarized in Table 1.

The CLPS plasma generator test results reported here are for the first industrial prototype produced by RCA. The testing has provided valuable operational experience, and has confirmed the soundness of the fundamental design.

Source Design

Assembly drawings of the LBL baseline design for the CLPS are shown in Figure 1. A number of papers detailing the mechanical design and fabrication have been presented at this conference. The CLPS and the LPA prototype accelerators use the same water cooled grid shapes and gaps. The CLPS grids have been lengthened from a 10 cm to a 12 cm slot length. Both are electrostatic tetrode designs, with each of the four electrodes made up of four grid modules. The

*This work supported by U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

grid modules are made of stainless steel grid holders, with the molybdenum grid tubes brazed into place.[10] The nominal 39 cm length of the LPA has beeen increased to 48 cm in the CLPS by increasing the number of grid tubes in each module from 11 to 12 (i.e., each electrode went from 44 to 48 grid rails). The manifolding for the 150 psi cooling water is the similar in both cases, using the individual grid tube holders to carry water between the grid tubes and corona rings, which are used as manifolds.

Table 1. Projected CLPS Performance

	TFTR	MFTF-B	GA Big-D
Voltage, kV	120	80	80
Aperture	12cm x 43cm	12cm x 48cm	12cm x 48cm
Gas	D	D	H
Current, Apmeres	70	60	80
Atomic fraction	≥ 80 %	≥ 80 %	≥ 80%
Pulse, seconds	2	30	5
Focus, meters	∞	10	10

The most significant differences between the LPA and CLPS accelerators are: Accelerator insulator; Plasma grid mask; and Focusing of the CLPS. The LPA used a ceramic insulator stack, brazed to stainless steel corona rings and flanges. The CLPS insulator stack is made of bonded epoxy. The CLPS has two sizes of source grid mask: 12 x 43 cm for TFTR; and 12 x 48 cm for MFTF-B and GA. The smaller aperture is required for TFTR to fit the existing beamline apertures. The LPA used unfocused (flat) electrodes, and the CLPS modules supplied for TFTR will also be unfocused. Requests for a ten meter focal length from MFTF-B and GA were accomodated by inclining the outer two modules by means of shims. The ground plane electrode modules have been designed with overlapping skirts to keep neutralizer plasma from the suppressor grid when the modules are inclined.

The LPS and CLPS plasma generators share a number of common features:

- Copper bucket.
- Nominal 3 kG sumarium-colbat magnets, with axial line cusps on the bucket sidewalls.
- Multiple bent hairpin filaments made of 60 mil tungsten wire, mounted in parallel on the cathode plates (Referred to as the filament sandwich).
- Gundrilled water cooled sidewalls and backplate.

The use of a magnetic bucket plasma chamber has two operational effects: higher power efficiency and higher atomic fraction. Higher power efficiency is the result of better confinement of the primary electrons, which also allows higher arc voltages compared with a field free plasma source. For source pressures of a few millitorr, this design works best with arc voltage from 75 to 100 volts. Since the plasma level is basically determined by arc power, higher voltage means lower current and longer filament lifetime. Higher atomic fraction is the result of a virtual magnetic filter,[11] which keeps energetic electrons out of the volume in front of the accelerator.

The design of the CLPS plasma generator incorporates a number of improvements based on operating experience with the LPS. Most of the anode area is provided by the backplate and sidewalls, with the filament sandwich separated from anode by two electrically floating spacer plates. The plates are separated by 10 mil milar sheets, recessed from the plasma. Early experience with the LPS revealed that arc spotting was frequent and severe between the filament sandwich, spacers and anode. A molybdenum shield structure, mounted on the cathode plates, was developed for the LPS to keep line of sight plasma out of the gaps between the copper plates. Development testing revealed that metals which had higher melting temperature than copper were less susceptible to spotting damage at the voltages and plasma levels of interest. Consequently, the CLPS design was given a dull nickel plate on the two filament and two spacer plates, with line of sight overlaps to keep plasma out of the insulator gaps. This has proven very successful during initial testing of the first industrial CLPS plasma generator from RCA. No spotting damage has been sustained during conditioning, and source reliability has significantly improved.

Another difference between the LPS and CLPS plasma generators is a slight increase in anode area for the CLPS. The original LPS anode was the line cusp areas on the sidewall and backplate. This proved to be marginal for deuterium and impossible for hydrogen - the LPS was unstable to an inefficient mode with an extended cathode sheath. In the LPS, anode was added by resistively tying the probe plate, which is near the extraction plane, to anode. In the CLPS, a one inch lip of copper was designed into the front of the bucket, just behind the probe plate. This has given reliable deuterium operation, with high atomic fraction. For hydrogen, the CLPS can be operated with the probe plate shorted to anode. Optimum hydrogen efficiency and atomic fraction can be obtained by resistively tying the probe plate to anode.

10 x 40 cm Prototype Accelerator Performance

The results of the three major testing programs carried out with the 10 x 40 cm prototype LPA/LPS are summarized in Table 2. The tests were carried out on the Neutral Beam Engineering Test Facility (NBETF) at LBL. Some of the results have been reported previously.[12,13] The most extensive testing was the 80 kV, 30 second 500 shot reliability test. Experience indicates that source availability improved with operation - to the point where the ion source was more reliable than major beamline components, such as the beam dump water system and power supplies. Hydrogen operation of the LPS prototype plasma source was more difficult than with the CLPS.

Beam species was measured with the OMA spectral diagnostics, which spectroscopically resolves doppler shifted atomic live radiation. Beam divergence was measured with the OMA, with an instrumented inertial target located about six meters from the exit aperture, and with an instrumented water cooled target at 11 meters. The LPA has established the basic performance grid design, and its ability to handle the power.

Operationally, the long pulse source appeared to be much easier to condition and to run more reliably than the LBL short pulse designs. Several factors may have contributed to this. The long pulse grids are larger in cross section than the grids. Although the metal to metal gaps are similar, the overall effect is to lower perveanve, i.e., the water cooled grids have a lower optimum current density. The inertial grids have always been run with the field-free plasma generators developed during the same era. The new magnetic bucket plasma generators have better plasma uniformity, higher atomic fraction, and run a lower gas pressure than the field-free type. All of these effects contribute to lower beam divergence and easier operation.

Table 2. Test results for the 10 x 40 cm LPA/LPS Prototype

Voltage	120	80 kV	80
Gas	D	D	H
Optimum current, Amps	66.5A	40.7	56.6
Atomic fraction	80%	83%	70%
Optimum beam divergence 1/e half angle	0.4^{o} x 0.73^{o}	0.35^{o} x 0.95^{o}	0.5^{o} x 1.0^{o}
Shots	100	500	100
Availability	85%	96%	90%

Based on the performance of the LPA/LPS prototype, the CLPS is expected to meet the user requirements listed in Table 1. The accelerator design is felt to be relatively well established. Any uncertainty in the performance of the accelerator is associated with the performance of the plasma generator, i.e., given the required plasma uniformity and atomic fraction, the accelerator is expected to deliver the scaled current and divergence.

CLPS Plasma Generator Performance

First article testing of the RCA built CLPS plasma generator on Test Stand IIA has demonstrated the soundness of the fundamental design, and revealed a number of minor adjustments. The dull nickel plating on the filament sandwich and spacer plates has made arc conditioning relatively spot-free.

The plasma profile is routinely measured by reading saturated positive ion current with an array of twenty probes biased at -22 Volts with respect to cathode. Plasma uniformity is measured as the percentage difference between the highest and lowest probes, with 15% being the maximum difference allowed for beam operation. The ion charge state distribution is measured with a magnetic momentum analyzer.[9] In a few months of testing, acceptable plasma uniformity, 10 - 15% has been achieved over the 12 x 43 cm TFTR area. The best 12 x 48 cm profile achieved to date is about 23%. The atomic species mix as a function of arc power is shown in Figure 2, as measured with a momentum analyzer.

Conclusions

The CLPS is the most powerful and compact of the long pulse positive ion neutral beam sources developed. Initial test results indicate that the production sources will meet the performance goals established by the user groups.

Acknowledgments

The authors are pleased to express their appreciation for the work of the operations staff-especially, D. Deutscher, C. Hauck, D. Kippenham, and J. Roberts.

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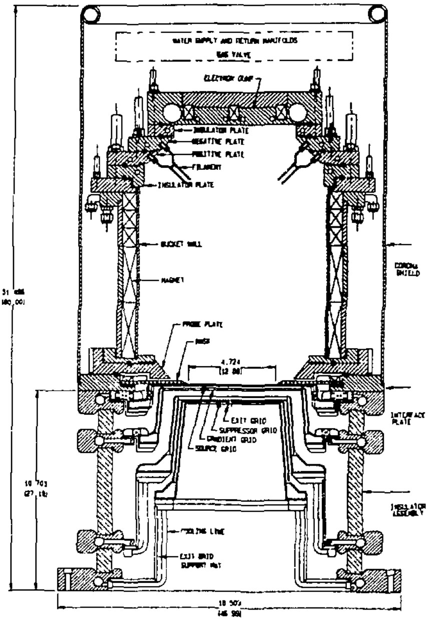

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Figure 1. Assembly drawing of the CLPS plasma generator and accelerator.

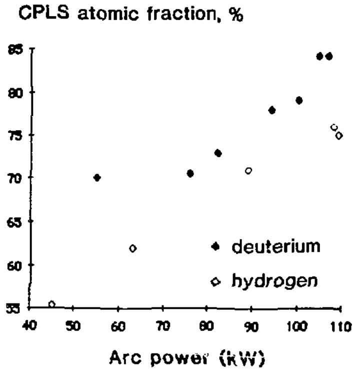

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Figure 2. Atomic fraction of the CLPS plasma generator as a function of arc power for hydrogen and deuterium.