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120 kV Testing of 10 x 40 cm Prototype of U.S. Common
Long Pulse Neutral Beam Source*

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Abstract

The 10 x 40 cm Long Pulse neutral beam source developed at Lawrence Berkeley Laboratory has been selected as the prototype for the design of the U.S. Common Long Pulse Source to be used on TFTR, Doublet-III, and MFTF-B. The Long Pulse Source consists of a magnetic line cusp bucket with an actively cooled backplate electron dump, and a four-grid accelerator using slot apertures and water-cooled molybdenum rails. Deuterium testing of the long pulse source at 120 kV, 53 A, and two-second pulse length has been completed on the Neutral Beam Engineering Test Facility, including an 8 hour, 100 shot test to demonstrate the durability and reliability of the source. Maximum 2 second beam parameters obtained (not simultaneously) are 125 kV, 58 A (deuterium), and 7.1 MW. Beam pulse length has been extended to 5 seconds at

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120 kV. Atomic species fractions in excess of 80% have been obtained, with a beam divergence (full energy, 1/e half angle) of approximately 0.8×0.4 degrees. Calorimetric measurements on the accelerator grids and backplate electron dump indicate heat loads consistent with predictions and within the design limits of the source. This testing has verified the design of the source, and its ability to exceed the basic performance requirements.

I. INTRODUCTION

Plasma heating for TFTR, Doublet-III, and MFTF-B will be provided primarily by neutral beam injection, employing the U.S. Common Long Pulse Source, currently being fabricated*. The prototype for this neutral beam source is the 10 x 40 cm long pulse source developed at Lawrence Berkeley Laboratory. The testing reported in this paper represents the second of two primary testing phases for this source, which have been conducted at the Neutral Beam Engineering Test Facility (NBETF). The first phase, in support of the MFTF-B program, consisted of 80 kV, 30 second deuterium beam testing, which has been completed and reported elsewhere.¹ This paper presents the results of the 120 kV, deuterium testing intended to support the TFTR program. The objective of this testing was to demonstrate reliable 2 second operation at 120 kV, with a beam current of 53 amperes or greater.

The production sources will be configured to provide 70 amperes of 120 kV deuterium in a 12 x 43 cm unfocussed beam for TFTR, 58 amperes of 80 kV deuterium in a 12 x 48 cm beam for MFTF-B, and 80 amperes of 80 kV hydrogen in a 12 x 48 cm beam for Doublet III. The MFTF-B and Doublet III sources will be of identical design, with angled accelerator modules providing a focal length

* RCA New Products Division.

of 10 meters. Plans call for the testing of the first production source at NBETF prior to operation on TFTR.

II. SYSTEM DESCRIPTION

The Berkeley long pulse source consists of a 57 x 24 x 30 cm (interior wall dimensions) magnetic cusp plasma generator, and a four-grid accelerator comprised of water cooled molybdenum tubes. The filaments are positioned along the rear corners of the plasma generator, behind a virtual electron filter formed by linked flux between the backplate and side wall cusp magnets. The design of the long pulse source is illustrated in Figure 1 and has been previously presented in detail.^{2,3}

The 120 kV testing was performed on the Neutral Beam Engineering Test Facility which includes a cryopumped beamline with an actively cooled beam target calorimeter. A Doppler shift spectrometer employing an optical multichannel analyzer (OMA) is located upstream of the neutralizer, providing beam species and divergence data. No separation magnet or ion dump was available for this testing, hence the target calorimeter was required to accommodate both neutral and ion beam components with a total power of up to 7 Mw. To minimize beam steering due to the proximity of the 184 inch cyclotron, correction coils were installed on the injector tank. The design and operation of the Neutral Beam Engineering Test Facility has been previously reported.^{4,5,6,7,8}

III. SOURCE OPERATION

The plasma generator operates with temperature limited emission from thirty-four 60 mil tungsten filaments, each carrying about 83 amperes of filament supply current and 32 amperes of arc current. The bucket walls and backplate constitute the anode, with the electron loss area reduced by the

presence of the magnetic line cusps. Additional effective anode area can be obtained by connecting the probe plate (located between the bucket and accelerator) to anode potential through a ballast resistor. A resistance of 60 milliohms was typically used in this testing, resulting in a probe plate potential of about 7 volts negative with respect to anode, with a current draw of 133 amperes (about 12% of the total arc current).

Arc voltage was normally between 70 and 80 volts. Higher voltages reduced arc efficiency, with the additional power dissipated on the bucket walls, and lowered the atomic species fraction. Lower voltages required low arc impedance, necessitating high filament power. Such operation tended to result in arc voltage oscillations, and was avoided.

The floating potential of the first accelerator grid provided a useful indication of the source operating condition. Under normal circumstances the grid floated approximately 15 to 20 volts negative with respect to the anode. A more negative floating potential would be an indication that too many primary electrons were reaching the grid and that the magnetic filter, intended to confine primary electrons to the rear of the source, was not sufficiently effective. Highly negative floating potentials also occurred during inefficient mode operation, when the plasma potential became negative and primary electron power dissipation occurred at the anode sheath. This mode of operation could be avoided by providing adequate gas feed rate and sufficient anode area to keep a positive space charge in the source plasma. Further details of the development of the plasma generator and its operating characteristics are presented elsewhere.⁹

The dependence of the LPS operating characteristics on filament temperature necessitates careful control of filament power for reliable source operation. A variety of control techniques have been employed to maintain stable and repeatable source plasma conditions for beam operation. After

several seconds of filament warmup time the filament power is reduced when the arc is turned on. With the contribution of arc current to filament heating, this scheme maintains constant arc conditions. To compensate for power supply drift a feedback regulator is available which monitors saturated positive ion current to a probe biased -22 volts with respect to cathode, and adjusts the arc supply SCR phasing signals to maintain a preset ion saturation current level.

As beam voltage was increased to 120 kV it became apparent that backstreaming electron power was contributing substantially to an increase in plasma density when the beam was switched on. The backstreaming electrons lower the arc impedance probably by contributing to ionization, or by indirectly heating the filaments. Both effects may be involved since an instantaneous density increase as well as a long time constant increase are observed. To compensate for this drop in arc impedance it was found advantageous to further lower filament power with beam turn-on. This arrangement permitted reliable long pulse beam operation with steady arc and beam conditions.

The need to adjust filament power to compensate for backstreaming beam power did not arise during 80 kV testing. Backstreaming power at 80 kV, 40 A with 12 Tl/sec deuterium was approximately 30 kW to the entire plasma generator, compared to a total arc and filament power of 90 kW. For 120 kV, 53 A, 14 Tl/sec deuterium the backstreaming power was approximately 100 kW, compared with a total arc and filament power of 105 kW. While a large part of the backstreaming power is expected to be dissipated directly on the electron dump with no effect on the arc, it is apparent that some portion contributes secondary electrons or provides indirect heating of the filaments, necessitating the compensation, discussed above, at the higher beam power levels.

With a typical gas feed rate of 14 Tl/sec the approximate pressure was 10 mTorr in the source, 2 mTorr in the neutralizer, 4×10^{-6} Torr in the injector tank, and 10^{-5} Torr in the target tank.

IV. BEAM TEST RESULTS

Optimum perveance was determined by calorimetric divergence measurements. Figures 2 and 3 show calorimetric tunes for 90 kV and 120 kV operation, respectively. A reliable operating range of approximately 15% is indicated in both cases. At 90 kV optimum perveance is found to be 1.24 micropervs (33 Amperes), and at 120 kV optimum is 1.27 micropervs (53 Amperes). Tunes based on doppler shift spectroscopy and target power fraction are included, which indicate reasonable agreement with the calorimetric divergence tunes. Minimum beam divergence, expressed as a 1/e half angle perpendicular to and parallel with the accelerator rails, was 0.79×0.46 degrees at 90 kV and 0.86×0.60 degrees at 120 kV, as measured by target calorimetry. These compare with spectroscopically determined values of 0.81×0.41 degrees at 90 kV and 0.91×0.51 degrees at 120 kV for the total beam. Since both neutrals and ions are deposited on the target, stray magnetic fields may contribute to the fact that the calorimetric parallel divergences are larger than the OMA results, which are obtained immediately downstream of the accelerator. As expected, OMA data for the full energy component alone showed tighter divergences of 0.68×0.33 degrees at 90 kV and 0.78×0.40 degrees at 120 kV.

The increase in perveance with increasing beam power is, in part, associated with the improvement in atomic species fraction observed to occur with increasing ion current density. At 90 kV beam voltage the arc power at optimum perveance is approximately 58 kW, providing an ion saturation current of 170 mA/cm^2 . The resulting species fractions are 77% D_1^+ ; 12% D_2^+ ; and 11% D_3^+ , at 17 Tl/s gas feed rate. At an arc power of 85 kW,

required for 120 kV beam operation, the current density is approximately 240 mA/cm² with species fractions of 80% D₁⁺; 16% D₂⁺; and 4% D₃⁺, at 14 Tl/s. This higher atomic fraction would be expected to increase perveance approximately 2%. The dependence of species fraction on arc power and gas feed rate is presented in Figure 4.

Beam divergence is also found to be a function of gradient grid voltage. Figure 5 shows the variation in beam divergence, determined by OMA, perpendicular to the grid rails, at optimum perveance for the range of gradient grid voltages tested during 120 kV operation. The source was typically operated at a first gap voltage, V_{1-2} , of 14.5% of V_{accl} (ie. 103 kV gradient grid potential for 120 kV accel voltage) which was found to provide a good compromise between beam divergence and perveance. Raising the gradient grid voltage to 105 kV lowered the optimum perveance from about 1.27 to 1.20 micropervs.

During four to five second beam operation at 90 kV, time-dependent divergence and species were observed. Target panel water temperatures, which normally equilibrate in about one second, were observed to fall in the central panels while rising in the outer panels over a time scale of several seconds. At a 17% gradient grid voltage ratio and 16 Torr-liter/sec gas feed rate, OMA species measured during a 300 msec window at various times throughout the shot showed a decline from 80% atomic at the beginning of the shot to 70% atomic within 3 seconds. Similarly, the full energy perpendicular divergence measured by OMA rose from 0.78 degrees to 0.98 degrees over that time period.

On the speculation that grid heating and distortion could be responsible for the time-dependent divergence, the accelerator was removed and examined. A small number of grid rails were found to be outside the normal alignment tolerances. The accelerator was re-aligned and testing resumed. The perpendicular beam divergence was improved by the re-alignment, and its

time-dependence substantially reduced. The probable cause of the drop in atomic species fraction with beam on-time was found to be outgassing of the polyethylene gas feed lines. The gas fittings entering straight into the rear of the source permitted backstreaming electrons to bombard the inside of the polyethylene tubing. A darkening of the tube interior was observed in regions exposed by line-of-sight to the accelerator. It was postulated that hydrocarbon contamination released as the tubing heated altered the plasma conditions. Moving the gas feeds to the top and bottom of the source, protected from high energy electrons, eliminated the time-dependent species effect, and further reduced the time-dependence of the divergence. Maintaining gas feed rates less than 16 Torr-liter/sec and the gradient grid voltage ratio less than 17%, in addition to the changes noted above, fully eliminated any time-dependent beam behavior.

To demonstrate the reliability of the plasma generator and accelerator designs, a test consisting of 100 beam shots of 2 seconds duration at 120 kV was performed over an 8 hour period. This test was conducted without use of the feedback regulator to provide a worst case appraisal. Except for periods during which line voltages were changing severely, source availability was greater than 85%.

The high voltage switching and crowbarring circuit was timed to interrupt the beam for 20 msec following a fault signal. Data indicated an average of 2.8 interrupts per shot during the reliability testing. The interrupt frequency data is provided in Figure 6 for the two best days of operation, covering approximately 165 shots.

During the 100 shot testing beam voltage and current were increased above design values as an over-test of the source. Operation was satisfactory at voltages as high as 125 kV, and currents up to 58 amperes. A maximum 2 second beam power of 7.1 MW was obtained. Pulse lengths up to 5 seconds were

obtained at 120 kV. Typical operating parameters for the long pulse source at 90 kV and 120 kV are provided in Table I.

One anomaly was observed in the beam profile. Target calorimetry indicated that the beam was slightly rotated in the counterclockwise direction. Examinations of the accelerator exit region indicated that the divergence of the beam was higher in the lower left and upper right corners than in the other two corners. Since the source is most often operated underdense it can be concluded that these regions are at slightly lower density (and thus higher divergence) than the source average. This observation agrees with the calorimetrically measured lower beam power in the lower left and upper right corners. The reason for this anomaly may lie in the configuration of the magnetic cusp lines in the bucket wall. There are 36 cusp lines of alternating polarity spaced around the bucket, 9 in each quadrant. The odd number of cusps per quadrant results in two quadrants that interact strongly with the unbalanced magnetic flux from the backplate, with the other two interacting less strongly. The coupled flux is oriented such as to cause an upward drift of primary electrons in the lower left, and a downward drift in the upper right. The result would be a decrease in plasma density in these two quadrants. The slightly larger Common Long Pulse Source, scheduled to begin testing in late 1985, is designed with 10 cusps per quadrant and should not exhibit this effect.

V. CALORIMETRY

For long pulse, high power operation the thermal design of the accelerator grids and the backplate electron dump are of particular interest. The water-cooled accelerator grids have been designed to sustain up to 1000 continuous watts per rail, and the backplate electron dump is configured to dissipate approximately 60 kW for 2 seconds. As expected, the heat loads on

the grids and electron dump varied with gas feed rate and, to a lesser degree, with perveance and gradient grid voltage. These results are presented in Figures 7 and 8. The grid peak powers indicated were determined from temperature rise measurements in the water lines several feet from the source, and are therefore a slight underestimate, but reflect the relative effects of gas feed rate and perveance. For grids 1 and 3, the fractional power absorption is independent of perveance. For the exit grid (grid 4) a greater fraction of the beam power is dissipated with increasing perveance, likely the result of a widening beamlet. It was observed that at a lower gradient grid voltage, which is predicted to produce a narrower exit beamlet, the exit grid power was lower and less sensitive to perveance. A similar but less pronounced dependence on perveance is observed for the gradient grid (grid 2) heat loads.

Consistent power transmission to the target dump was obtained during the testing. Figure 9 displays the frequency of occurrence for a given percent power deposition. The data indicate a strong peak at 84 to 86% power deposition. The data at 73% to 75% were taken during operation with a target water leak. During these beam shots, water from target leaks contaminated the arc and altered the perveance match, resulting in poor beam optics. Such shots displayed increased heat loads on the beamline scrapers and limiters.

It was possible to account for approximately 100% of the total beam power by monitoring the heat deposition on all exposed beamline surfaces. For a typical shot, 84% of the beam power reached the target; 2.4% was collected on beamline scrapers and limiters, 1.5% on target entrance limiters, 4.1% on the neutralizer walls, 6.5% on the OMA box surfaces, 0.5% on the accelerator grids, 0.8% on the arc chamber walls, and 0.6% on the backplate electron dump.

VI. DISCUSSION

The Berkeley long pulse source and accelerator have been successfully tested at 120 kV, 2 seconds with over 53 amperes deuterium extraction. This testing has demonstrated the operability and durability of this source design, on which the U.S. Common Long Pulse Source is based. The adequacy of the Neutral Beam Engineering Test Facility for high power operation has also been demonstrated, with target power densities of up to 2000 watts/cm². The long pulse beam power of 7.1 megawatts has been the maximum operated at this facility. Testing of the Common Long Pulse Source will involve beam power up to 8.4 megawatts. This testing is scheduled to begin in late 1985.

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REFERENCES

1. M.C. Vella, P.A. Pincosy, C.A. Hauck, and R.V. Pyle, Report on the Engineering Test of the LBL 30 Second Neutral Beam Source for the MFTF-B Project, LBL-17550, August 1984, to be published.
2. J.A. Paterson, G.W. Koehler, R.P. Wells, and L.A. Biagi, Proc. 8th Symposium on Engineering Problems of Fusion Research, IEEE Pub. No. 79 CH 1441-5NPS, p. 1065 (1979).
3. J.A. Paterson, G.W. Koehler, and D.P. Yee, Proc. 9th Symposium on Engineering Problems of Fusion Research, IEEE Pub. No. 81 CH 1715-2NPS, p. 233 (1981).
4. J.A. Paterson, L.A. Biagi, M. Fong, G.W. Koehler, W. Low, P. Purgalis, and R.P. Wells, Proc. 10th Symposium on Engineering Problems of Fusion Research, IEEE Pub. No. 83 CH 1916-6, p. 1526 (1983).
5. J.A. Paterson, G. Koehler, and R.P. Wells, Proc. 9th Symposium on Engineering Problems of Fusion Research, IEEE Pub. No. 81 CH 1715-12, p. 1666 (1981).
6. I.C. Lutz, C.A. Arthur, G.J. deVries, and H.M. Owren, Proc. 9th Symposium on Engineering Problems of Fusion Research, IEEE Pub. No. 81 CH 1715-12, p. 427 (1981).
7. K.H. Berkner, V.L. Jacobson, J.A. Paterson, P.A. Pincosy, H.M. Owren, R.L. Kilgore, The 13th Symposium on Fusion Technology, Varese, Italy, September 1984.
8. V.L. Jacobson and E. Theil, The 13th Symposium on Fusion Technology, Varese, Italy, September 1984.
9. P.A. Pincosy, K.W. Ehlers, A.F. Lietzke, H.M. Owren, J.A. Paterson, R.V. Pyle, M.C. Vella, LBL-17604, to be published.

Table I

	<u>90 kV</u>	<u>120 kV</u>
Accel Voltage	89 - 93 kV	119 - 125 kV
Beam Current	31 - 35 A	51 - 57 A
Perveance	1.15 - 1.33 up	1.18 - 1.34 up
Arc Voltage	67 - 78 V	67 - 78 V
Arc Current	725 - 800 A	1050 - 1150 A
Filament Current	3000 - 3200 A	2500 - 2800 A
Gas feed (D ₂)	11 - 16 Tl/s	12 - 17 Tl/s
Divergence (1/e half angle)		
OMA full energy	0.68° x 0.33°	0.78° x 0.40°
OMA total beam	0.81° x 0.41°	0.91° x 0.51°
Calorimetric	0.79° x 0.46°	0.86° x 0.60°
Species % (full:1/2:1/3 energy)	77:12:11	80:16:4

FIGURE CAPTIONS

- Fig. 1 The Berkeley 10x40 cm long pulse source and accelerator.
- Fig. 2 Perveance tune at 90 kV, 15% gradient grid ratio (V_{1-2}/V_{accel}), and 17 Torr-liter/sec deuterium. (a) Divergence determined from target calorimetry and OMA data. (b) Percent beam power deposited on target, based on calorimetry.
- Fig. 3 Perveance tune at 120 kV, 15% gradient grid ratio, and 14 torr-liter/sec deuterium. (a) Divergence determined from target calorimetry and OMA data. (b) Percent power deposited on target, based on calorimetry.
- Fig. 4 Deuterium species fraction as a function of arc power, showing full energy, half energy and third energy components (corresponding to D_1^+ , D_2^+ , and D_3^+) for gas feed rates of 12-14 Torr-liter/sec and 16-17 Torr-liter/sec.
- Fig. 5 Optimum divergence, determined by OMA, as a function of gradient grid ratio (V_{1-2}/V_{accel}), at 120 kV, 14.5 Torr-liter/sec deuterium.
- Fig. 6 Frequency of beam interrupts during 2 second, 120 kV reliability testing.
- Fig. 7 Accelerator grid heat loads (as a percentage of beam power) as a function of perveance, for 120 kV, 12.6% gradient grid ratio. Curves for 14.3 Torr-liter/sec and 16.4 Torr-liter/sec are shown. Optimum perveance for this case is approximately 1.23 micropervs.
- Fig. 8 Power dissipated on backplate electron dump as a function of gas feed rate and gradient grid voltage (V_{1-2}).
- Fog. 9 Percent beam power dissipated on target during 120 kV reliability testing.

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Figure 1

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Figure 2

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Figure 3

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Figure 4

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Figure 5

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Figure 6

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Figure 7

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Figure 8

XBL 8510-4283

Figure 9

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