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Experimental results from a diagnostic beamline for the PBX-M experiment

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The experimental performance of a high-brightness neutral-beam system is described which has been designed and manufactured by Culham Laboratory under contract to the Princeton Plasma Physics Laboratory. The neutral beam serves as a diagnostic on the PBX-M experiment and is used to perform studies of high-beta, bean-shaped, neutral-beam-heated plasmas, and plasma-current profile shaping using ion Bernstein wave and lower hybrid rf systems. A maximum extracted current of ~ 2.7 A of positive hydrogen ions at 80 keV has been obtained from a multiaperture extraction system. The full-energy H^0-equivalent neutral-current density measured 370 cm from the extraction plane was ~ 6 mA cm^{-2}.

INTRODUCTION

A diagnostic beamline has been designed and manufactured for PBX-M based on a similar system built for TEXT.[1] The physics requirements for the system described here require that the full-energy neutral beam delivered to a point on axis 400 cm from the extraction plane should have a current density between 3 and 6 mA cm^{-2} with an energy range of 60–80 keV. The system would be pulsed with pulse lengths up to 100 ms duration at 5-min intervals and be capable of operation in the stray fringing magnetic fields of PBX-M. Culham was responsible for the detail design of the plasma source, the extraction system, the neutralizer, and associated equipment to meet these objectives.

I. BEAMLINE DESCRIPTION

Figure 1 shows the beamline hardware. The assembly is designed to fit into an existing sector on PBX-M with the facility for changing the injection tangency angle by about 25°. The beam is extracted from a magnetic multipole-type plasma source identical to that used on TEXT. The extraction system is a four-electrode multiaperture array consisting of 19 circular apertures with identical aperture sizes as TEXT, but the gaps and insulators have been scaled for 80-keV operation (Fig. 2). Focusing of the individual beamlets is achieved by the "offset" aperture method[2] where by displacing the aperture in grid 3, the individual beamlets are inwardly focused to a point on-axis 400 cm from the extraction plane. The auxiliary supplies, filament, and arc are from transformer/rectifier sets with the HT and protection/regulation coming from a dc power supply and mod-regulator tube,[3] previously used on the commissioning of the TEXT beamline.

In order to simulate the PBX-M geometry for the system acceptance tests, an extension tube was fitted to the beamline with a target calorimeter at 370 cm from the extraction plane. The calorimeter consists of an array of small individual calorimeters, with built-in thermocouples, en-

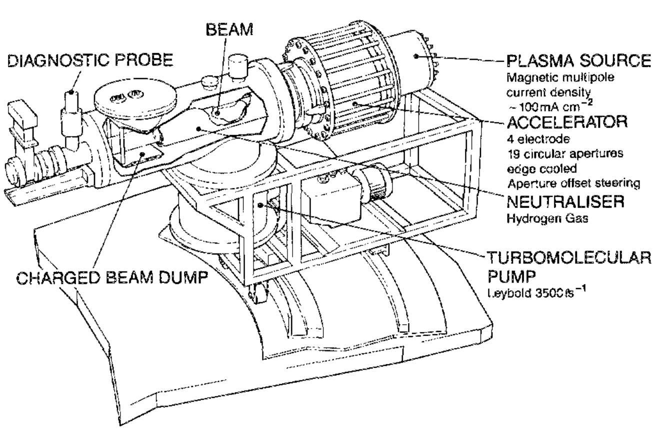

FIG. 1. General view of beamline components.

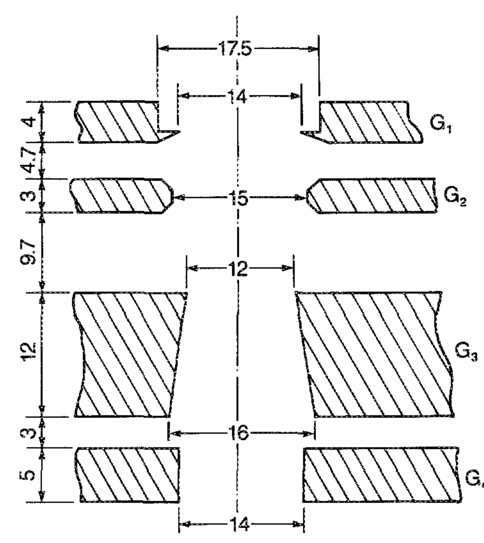

FIG. 2. Profile of apertures and grid spacing (dimensions in mm).

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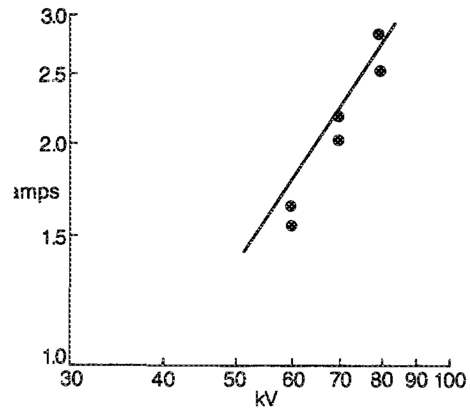

FIG. 3. Total extracted current as a function of beam energy at minimum divergence. The solid line is the predicted performance.

abling beam profile and power density measurements to be made.

II. OPERATION AND EXPERIMENTAL RESULTS

A. Operation

The extraction system was first conditioned to 85 kV (grid 2–grid 3) using a low-current power supply < 1 mA. The system was then connected to the full-rated supply, with a 200-K resistor in series to limit the fault current, and conditioned once again, first without and then with source gas.

The plasma source was conditioned by raising the arc current in 25-A steps up to a maximum of 250 A. With previous extraction systems, it was found beneficial to condition grid 3, prior to attempting to extract beam, by pulsing the arc with negative volts on grids 3, but without extraction volts, and this procedure was carried out. Beam was extracted starting at 25 keV, and after a total beam on-time of 3 min, the system was operating reliably at 80 keV. Adequate neutralization was achieved with source gas only, and all the results were obtained with this mode of operation.

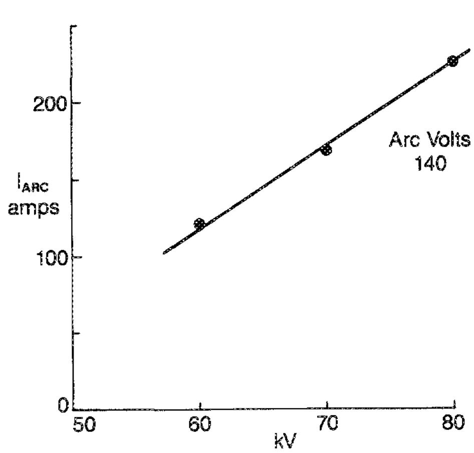

FIG. 4. Arc current as a function of beam energy at minimum divergence.

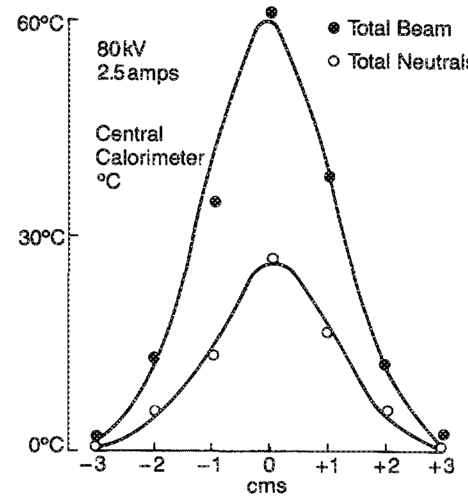

FIG. 5. Gaussian fit of beam profiles for total extracted current and total neutrals at 80 keV and minimum divergence.

B. Results

The total extracted current at minimum divergence (half width at $1/e$) over the range of extraction voltage was determined by optimizing the central power density on the target calorimeter (Fig. 3). The solid line is the predicted performance. The arc current was also recorded and is shown in Fig. 4.

A typical beam profile measured at 80 keV for both total and neutral beam is shown in Fig. 5.

The minimum divergence condition is determined by varying the total extracted current (by changing arc current) and this is illustrated in Fig. 6.

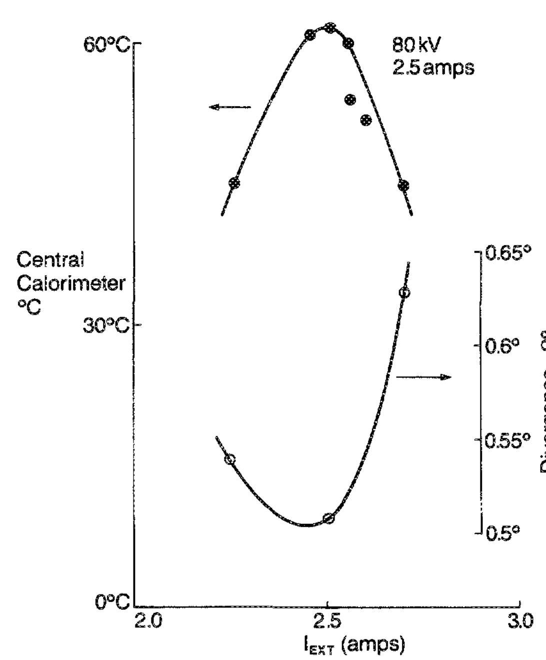

FIG. 6. Total extracted current as a function of I_{ext} at 80 keV (upper curve). Divergence as a function of total extracted current (lower curve).

TABLE I. Summary of experimental results.

E (kV)	I_{ext} (A)	Divergence (Ω)	$J_0(E)$[a] (mA/cm^2)	Total[b] transmitted current (A)
60	1.65	0.49°	6.8	1.2
	1.55	0.47°	7.2	1.17
70	2.2	0.5°	6.6	1.58
	2.02	0.48°	6.75	1.59
80	2.5	0.52°	5.5	2.0
	2.85	0.49°	7.13	2.13

[a]Calculated assuming species ratio H_1^+, H_2^+, H_3^+ of 50:20:30 and neutralizer target thickness of 200 mTorr cm.
[b]Calculated using divergence measured from beam profile.

Table I summarizes the performance that has been achieved during the commissioning phase.

During the commissioning phase, a variation of $\sim \pm 12\%$ was observed in the results, as shown in Fig. 3 and Table I, and we assume this to be a measure of the accuracy of the experimental measurements.

III. SUMMARY

The required specification for a diagnostic H^0 beam, based on physics requirements of 3–6 mA cm^{-2} of full-energy neutrals on-axis over the energy range 60–80 keV has been successfully achieved. The basis of our design has been confirmed and gives confidence in predicting the performance of similar systems in the future. One very important aspect was how quickly the system conditioned up to the 80-keV operational level and its high degree of reliability. The system is now installed and operating on PBX-M.

[1]J. R. Coupland, D. P. Hammond, J. W. Mepham, and O. J. Hancock, in *Proceedings of the 12th Symposium on Fusion Engineering*, Monterey, CA, Oct. 1987 (IEEE, New York, 1987).
[2]A. J. T. Holmes and E. Thompson, Rev. Sci. Instrum. **52**, 172 (1981).
[3]J. B. Hicks *et al.*, in *Proceedings of the 12th Symposium on Fusion Technology*, Julich, 1982, Vol. 1, pp. 419–424.