Title
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Authors
Berkner, K.H.
Cooper, W.S.
Pyle, R.V.

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LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

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K. H. Berkner, W. S. Cooper, and R. V. Pyle

Lawrence Berkeley Laboratory
Berkeley, California 94720

Abstract

A calculational and experimental program to optimize the extractor design of high-current multiple-aperture ion sources is in progress. In general, the computed and measured properties of extractors with circular apertures agree well. Very preliminary tests with a multiple slot extractor are encouraging.

Introduction

A calculational and experimental program to optimize the extractor design of high-current, multiple-aperture ion sources is in progress. The immediate goal is the production of a pulsed 20A, 20 keV deuterium ion beam, and its conversion into a neutral beam for injection into the 2X II controlled nuclear fusion experiment at the Lawrence Livermore Laboratory. The development of a large-area plasma source from which to extract ions is described in an accompanying paper.[1]

The geometry of the 2X II experiment sets a maximum useful beam divergence of about ±2 degrees. Since magnetic focusing of the ion beam before neutralization would result in a different focal point for each ion species in the beam (they differ in q/m) and consequently in loss of beam, and since beam energy modulation is easier if there is not a magnetic field to modulate, we decided to attempt an extractor design to generate an ion beam of small enough initial divergence that additional magnetic focusing would not be required. The elimination of a magnetic lens also permits beam neutralization close to the extractor.

The extractor design was carried out with the aid of a computer program originally written by Kirstein and Hornsby[2] and modified by Bate.[3] This program accepts as input the shape of the boundary, the potentials on the boundary, and the region which emits ions. Output consists of ion trajectories (space charge effects are included) and the ion current density J_+ at various points on the emitting surface. The electrode shapes were repeatedly modified until acceptable ion trajectories were obtained and j_+ was constant to ±5% across the emitting surface; the latter condition is consistent with a uniform plasma of the correct density as the emitter.

A typical electrode geometry for a single-circular-aperture is shown in Fig. 1; relative electrode potentials and equipotential contours are indicated. The electrode shapes are the result of the computer-aided design procedure just described. While the figure shows a single circular hole design, we plan to use arrays of slots in the final extractor.

We constructed four single-aperture extractors of copper based on this computed design;[4] they differed from one another only in the diameter of the counterbored hole in the beam-forming electrode, which ranged in diameter from 2.73 mm (the optimum of the computed design) to 2.09 mm (a straight-sided hole). To evaluate them we used them to extract ions from a deuterium plasma produced by a hollow-cathode arc discharge, and measured the power delivered to three concentric calorimeters subtending half-angles of 0.95, 1.90, and 3.45 deg, located 79 cm downstream. The beam line was filled with D_2 at a pressure of about 5 mtorr, so the beam at the calorimeter consisted largely of neutral particles. The energy range covered was 10 to 20 keV. No magnetic focusing was used. For this application the experimentally optimum extractor design was extremely close in shape to the computed optimum design.

We constructed and tested a multiple-aperture extractor of this experimentally optimized design; there were 19 holes 2 mm in diameter and 3 mm center-to-center, in a hexagonal array. Probe measurements in the plasma indicated that the saturated ion current density across the 19-hole array varies by less than ± 10%. Heating of the extractor limited tests of this 19-hole array to beam energies between 2 and 16 keV. The performance of this 19-hole extractor was indistinguishable from that of 19 single holes.

The performance of both the (optimum) single- and multiple-aperture extractors can be summarized as follows: When the plasma density was adjusted for minimum beam divergence, the beams were gaussian in shape, and had 1/e half-widths ranging from 1.7 deg at 2 keV to 1.05 deg at 20 keV. For beam energies over 10 keV, less than 10% of the beam power was lost by electrode interception or in a poorly focused "halo." The measured perveance was within the values calculated for D and D_2 beams (we have not measured the beam composition), indicating that the assumed position and shape of the emitting plasma surface were very nearly correct.

In general, the computed and measured extractor properties agreed very well. While discrepancies do exist--for instance, the beam widths were larger than calculated, and furthermore were dependent on the beam energy--the performance of these extractors appears adequate for our purpose, and no additional magnetic focusing seems needed.

We have also designed and are testing a multiple-aperture extractor which uses slots rather than circular holes. Slots offer several potential advantages over circular holes, such as higher transparency, small beam divergence in the plane of the slots (presumably limited only by the thermal spread of ion velocities), and ease of mechanical design to accomodate thermal expansion of the extractor elements. Very preliminary tests with an extractor having four slots with rounded ends, each 2 mm wide and 11 mm long, with He^+ at 10 keV, indicate that about 80% of the current leaving the power supply was collected as equivalent current on the ± 3.45 deg calorimeter 79 cm away; of this, about 60% was in ± 2 deg. Comparable numbers for the extractor with the array of 19 circular holes with deuterium at 10 keV were 90% and 82%.

References

1. W. R. Baker, K. W. Ehlers, W. B. Kunkel, and A. F. Lietzke; Large-Area, High-Current Ion Source, p. . . .

2. P. T. Kirstein and J. S. Hornsby, IEEE Trans. Electron Devices ED-11, 196 (1964).

3. D. G. Bate, A Computer Program for the Design of High Perveance Ion Sources, UKAEA Culham Laboratory report CLM-R53, 1966 (unpublished).

4. W. S. Cooper, K. H. Berkner, and R. B. Pyle, Multiple-Aperture Extractor Design for Producing Intense Ion and Neutral Beams, Lawrence Berkeley Laboratory report UCRL-20698, 1971 (unpublished); submitted to Applied Physics Letters.

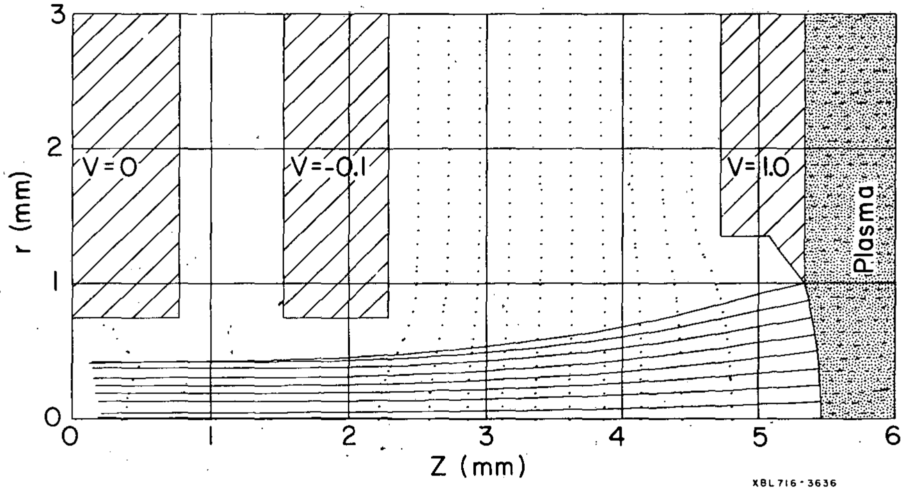

Fig. 1. Electrode geometry for a single-hole circular extractor, showing relative electrode potentials, equipotential contours, and ion trajectories.

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LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720