EXTRACTION OF SPACE-CHARGE-DOMINATED ION BEAMS FROM AN ECR ION SOURCE: THEORY AND SIMULATION

G. D. Alton and H. Bilheux

Physics Division, Oak Ridge National Laboratory[1]*,*
P.O. Box 2008, Oak Ridge TN 37831-6368, USA

This report elucidates the problem of extracting high quality space-charge-dominated beams from plasma sources, in general, and high charge-state ECR ion sources in particular, *with* and *without* strong magnetic fields in extraction gaps, through both theoretical analysis and computational study of the problem. An all-permanent magnet, 6-GHz ECR source[2], equipped with a remotely positional extraction electrode system[3-5] for affecting changes in the extraction gap, was used as the basis of a series of simulations to give insight into the extraction process. From these studies we find that extraction of high quality space-charge-dominated ion beams constitutes an optimization problem centered about finding an optimal concave plasma emission boundary that minimizes half-angular divergence for a given charge-state, independent of the presence or lack thereof of a magnetic field in the extraction region[3-5]. Under minimum half-angular divergence conditions, the plasma emission boundary has an optimum curvature and the perveance, P, current density, j_{+ext}, and extraction gap, d, have optimum values for a given charge-state, q. Optimum values for each of the independent variables (P, j_{+ext} and d) are found to be in close agreement with those derived from elementary analytical theory for extraction with simple two-electrode, parallel-plate or spherical geometry electrode systems, independent of the presence of a strong magnetic field in the extraction gap. This agreement enables the use of analytical expressions for predicting optimum extraction-gap settings that are crucially important operational parameters for extraction of highest quality, space charge-dominated beams. The action of strong magnetic fields, used to confine plasmas in the axial direction of these sources, modifies the character of beams during extraction through increases in angular spread and beam rotational effects. The emittances of individual charge-state beams, measured after M/q analysis, *with* and *without* strong magnetic fields in the extraction gap are essentially identical, suggesting that emittance growth due to aberrational and other non-linear effects attributable to magnetic field influences are small. In this report, the underlying theory is fully developed for extraction of space-charge dominated beams with parallel and spherical geometry extraction systems and compared with results derived from computational simulation studies for extraction of space-charge-dominated beams of varying mass, charge-state, and intensity.

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