Empirical Determination of Space Charge Compensation

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The application of neutral beam injection to fusion power plants demands significant enhancement of the electrical efficiency of these systems, possibly via improvements in neutralization efficiency and beam transmission. One solution, photoneutralization, will significantly reduce the gas density in the beamline, lowering the production rate of the beam plasma that provides space charge compensation and prevents excessive beam expansion. According to the steady state theory of space charge compensation [1] this should not result in increased space charge as the positive plasma ions accumulate within the beam potential until equilibrium is established when compensation is ~100%. However, there is evidence [2] that at pressures relevant to the photoneutralizer (<10^{-3}Pa) compensation is lower than predicted by the theory, increasing beam divergence and reducing transmission. Thus validation of the model is important for extrapolation to future systems but has been neglected experimentally.

This work presents a model of the evolution of the beam emittance under space charge that enables the degree of compensation to be established by comparison with measured emittance ellipses. The evolution of the ellipse of a beam expanding under space charge can be described by treating the space charge field as a continuous, diverging lens. Using matrix representation, the Twiss parameters of the emittance ellipse are evolved over distance for sequential application of the lens and drift space. Emittance growth due to phase-space distortion arising from a non-uniform beam distribution is included using the form in [3]. Space charge compensation modifies the beam current, affecting both the lens and emittance growth. Comparison of the dimensions and orientation of the measured ellipse and those computed for different values of compensation factor indicate the degree of compensation. Typical results for H^- beams of 10mA and 30mA each at 36keV are shown in Fig 1. The technique requires prior knowledge of the initial emittance ellipse, which can either be determined by beam optic code or by using two emittance scanners in sequence, as in [2]. This relatively simple technique will enable space charge compensation measurements to be made to validate the theory and so extrapolate to MeV/ampere class beams in low pressure environments. It will also allow investigation of the origin of the beam halo [4] which could limit the improvement in transmission necessary to achieve the efficiency demanded for future fusion power plant.

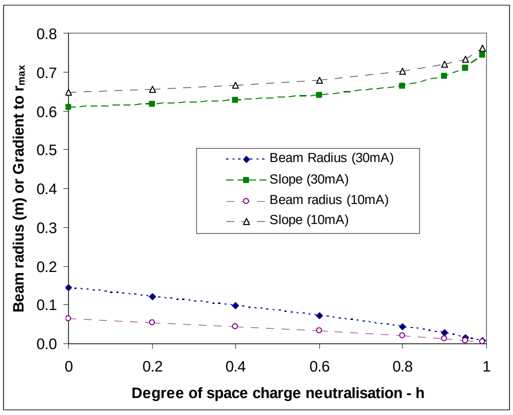

Fig 1 Beam envelope radius, r_{max}, and gradient between origin and r_{max} computed as functions of compensation factor h.

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[3] E.P. Lee, S.S. Yu & W.A. Barletta, Nucl. Fus. **21**, 961 (1981)

[4] E. Surrey, *11th Symp Production & Neutralization of Negative Ion Beams*, AIP Conf Proc 925, 278 (2007)