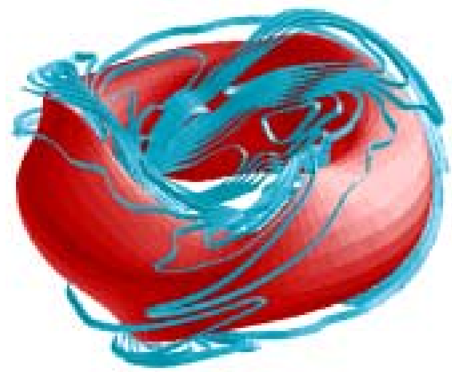

The Effect of

Fringe Magnetic Fields

On NCSX

Neutral Beam Injection System

Operation

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1. Introduction

The PBX-M Neutral Beam Injection systems where developed for the PDX project in 1978. The required magnetic shielding consists of magnetic enclosures for the Ion Sources and Neutralizers.

Fringe magnetic fields from toroidal devices effect the performance of Neutral Beam Injection systems by decreasing the extraction of current from the Ion Source, and by defocussing and deflecting unneutralized beam, thereby changing the pattern of power deposition on beamline components.

In order to estimate the impact of proposed NCSX field geometries on Neutral Beam performance, this Report documents the basis for the development of the present PDX Ion Source Magnetic enclosures, and the Neutralizer shielding. Then, the impact of increased fringe field intensities is discussed, possible shielding approaches, and implications for long pulse operation in moderate fringe fields.

2. Magnetic Field Ion Source Perturbation Tests

Fringe magnetic fields from a tokamak, for example, are usually vertical in the region of the Neutral Beamline ion source. The effect of this field on the Ion Source is to perturb the cylindrical symmetry of the plasma processes producing the extracted ion beam. In order to quantify this effect for the design of the PDX Neutral Beam ion source magnetic shielding, a magnetic field was applied to a 22cm PLT Ion Source on the PPPL PLT Neutral Beam Test Stand.[1] This field was produced using 2 Helmholtz coils spaced 64 cm apart. and arranged so as to apply field to the filament, anode and Accel grid regions of the Ion Source. A Hall Probe was used to measure the applied field, and it was calibrated using a Radio Frequency Laboratories Permanent Magnetic Calibrator which gave a reference field of 1000G $\pm$ 3/4%. The Ion Source was operated at 30.3KV, 40.0A. Fig. 1 shows the results of the measured percentage decrease in Accel current *versus* applied field. The solid line is a polynomial fit to the data. It is seen that an applied field of as little as 10G produces about a 4.5% decrease in Accel current. In the case of the larger volume PDX Ion Sources (30cm diameter grids) a greater sensitivity to applied field was expected.

3. PDX Ion Source Magnetic Shielding

Fig.2 shows the results of a calculation performed by L. Stewart to provide PDX Stray Field estimates *versus* major radius along the midplane for 500KA plasma with 22KA of Ohmic Heating current, 10KA of Equilibrium Field current, and 21 KA of Divertor field current.[2] These calculations were based individual stray fields taken from D. Brown et. al.[3] Fig. 3 is a log plot of same results for the region beyond 3m. The solid line is a Least-Squares-Fitted exponential which is extrapolated to the Ion Source region. It is seen that in the region of the Ion Source for both the Perpendicular and Tangential Injection locations for the Beamline, the fringe field in the Ion Source region was about 20G. In the case of the PLT Ion Source measurements (Fig.1) a magnetic shield attenuation of x25 would be acceptable. In the case of the larger volume PDX Ion Sources, a greater sensitivity to fringe was expected and an attenuation of x50 was sought in the magnetic shield design. The resulting design consisted of a rectangular shield fabricated from 0.5 inch thick Correy 99 iron plate, bolted to a low carbon angle iron frame and lined 0.5 inch thick lucite to provide electrical safety insulation. There have been no observable effects on Neutral Beam Ion Source performance when pulsed in sync with PDX, PBX, and PBX-M plasma operations.

4. PDX Neutralizer Cell Magnetic Shielding

Increased neutral beam divergence and deflection due to a transverse magnetic field is a well know.[4] The PDX Neutralizer Cell is magnetically shielded with 0.5 inch iron to provide about a factor of x50 attenuation of the fringe field. At the operating pulse lengths of 0.3-0.5s there were no observable effects on Neutralizer water calorimetry when operating in sync with plasma operations.

5. Other PDX Beamline Components

The PDX Neutral Beamline Ion Dump, Scraper Apertures, and Calorimeter water calorimetery never exhibited any changes attributable to fringe field effects when operating in sync with plasma operations at pulse lengths of 0.3-0.5s. Such asymmetries due to incident fringe field might be observable a longer pulse lengths and suitable diagnostics should be installed in anticipation of this possible effect.

Reionized power loss in the Transition Duct is turned into the duct walls and induces outgassing which increases reionization. The fringe field in this region is typically very high and no effort is made to magnetically shield Transition Ducts. A more effective approach is to attempt to reduce the neutral gas pressure in this region as much as possible by short, high conductance ducts and high pumping speeds.

6. Discussion

In conventional toroidal geometries, shielding the neutral beam ion source so as to minimize perturbations to normal ion source operation is often manageable because of the reduced fields at larger major radii and the small volume to be shielded. However, magnetic shielding of beamline power deposition surfaces is more difficult because these regions involve much higher fields and volumes, and uncertainties in ionic beam trajectory and changing neutralization efficiency along the beamline trajectory reduce the accuracy of design simulations. Hence, in the case of iron shielding the design problem is to determine exactly the amount of shielding needed to satisfy the shielding requirement, and thereby minimize the amount of perturbing magnetic material around the torus. The application of Helmhotz fields to compensate for stray fields is possible but this approach becomes less practical with increasing field strengths and large volumes.

The critical component is the Ion Source. Given a copious quantity of extracted beam, suitable power handling approaches can compensate for minimal beam defocussing and deflection due to fringe fields at shorter pulse lengths. As pulse lengths are increased suitable diagnostics need to be used to monitor for these effects.

References

1. H. W. Kugel and M. Ulrickson, "Measurement of Applied Transverse Magnetic Field on Performance of a PLT Neutral Beam Ion Source", PPPL Dec. 1978, unpublished.

2. L. Stewart, " PDX Stray Field Estimates", PPPL Memorandum, Feb. 22, 1979.

3. D. Brown, et al., "PDX Stray Field", PPPL, Aug. 1977.

4. J. Conrad, et al., "Enhanced neutral-beam Divergence Due to Imperfect Magnetic Shielding", J. Appl. Pys. 51(6), 2957 (1980). J. Conrrad, et al., "Experimental Measurement of Increased Neutral Beam Divergence Due to a Transverse Magnetic Field", J. appl. phys. 51(7) 3456 (1980).

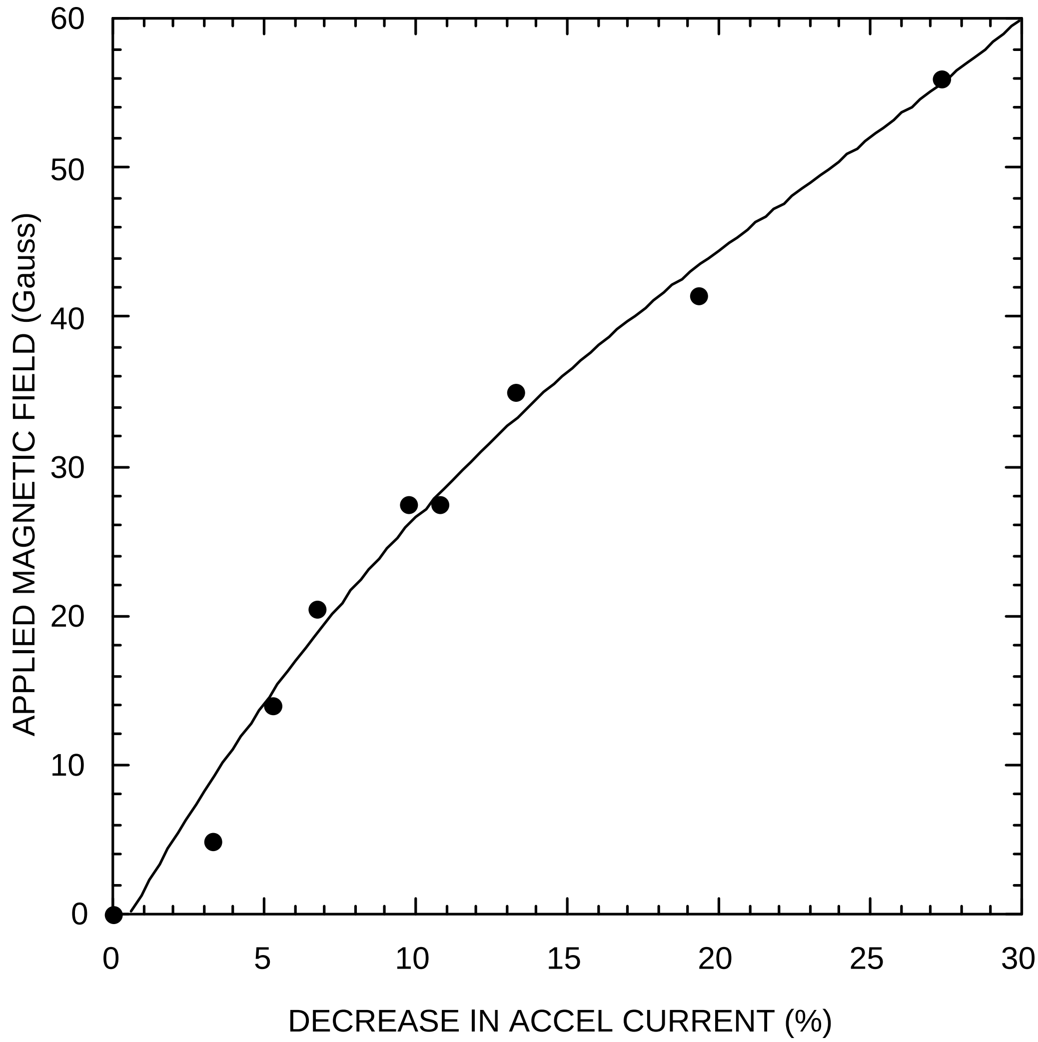

Fig.1 The results of the measured percentage decrease in Neutral Beam Ion Source Accel current *versus* field applied transverse to a 22cm PLT Ion Source using Helmhotz Coils. The Ion Source was operated at 30.3 KV, 40.0 A. The solid line is a polynomial fit to the data.

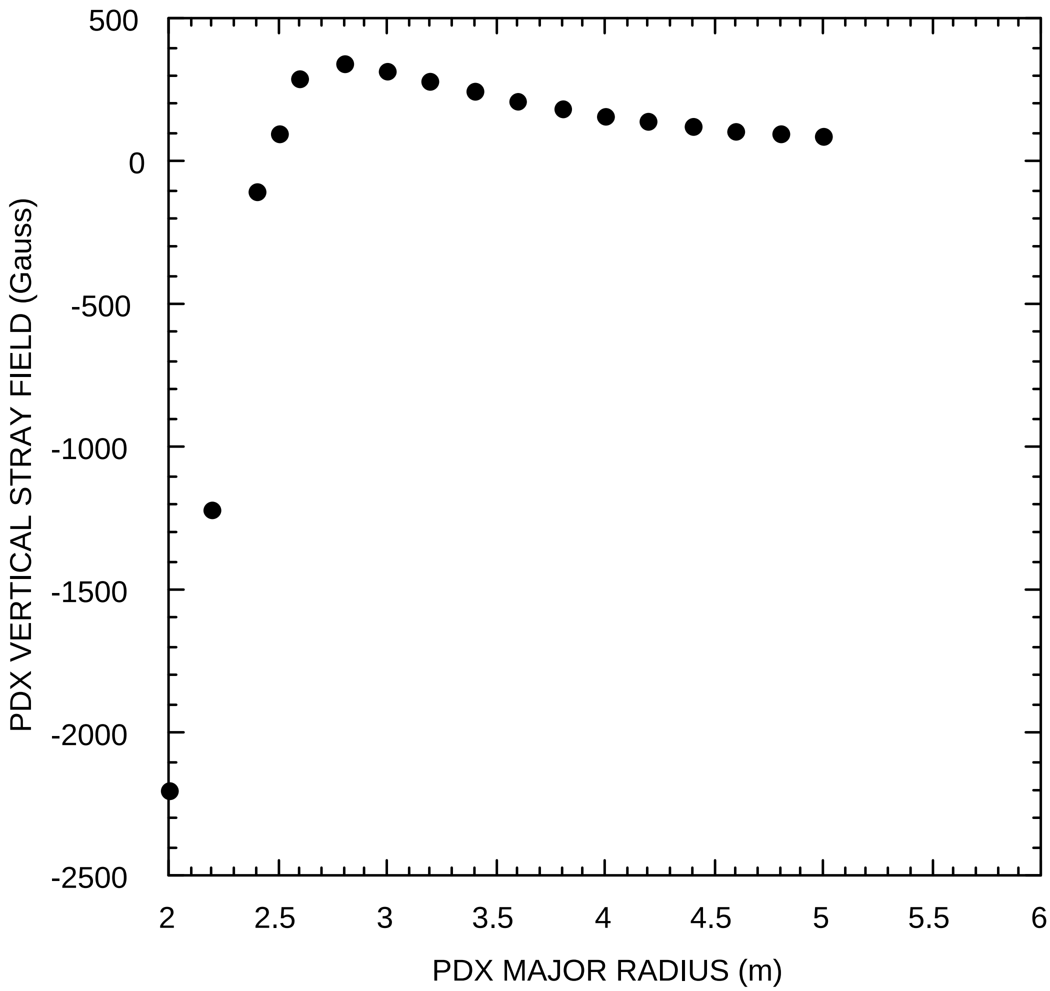

Fig.2. The results of a calculation by L. Stewart of PDX Stray Field estimates *versus* major radius along the midplane for a 500KA PDX plasma with 22KA of Ohmic Heating current, 10KA of Equilibrium Field current, and 21 KA of Divertor field current. [2] These calculations were based individual stray fields taken from D. Brown et. al.[3]

Fig.3 Log plot of the results shown in Fig.2 for the region beyond 3m. The solid line is a Least-Squares -Fitted exponential. It is seen that in the region of the Ion Source for both the Perpendicular and Tangential Injection locations for the Beamline, the fringe field in the Ion Source region was about 20G.