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by

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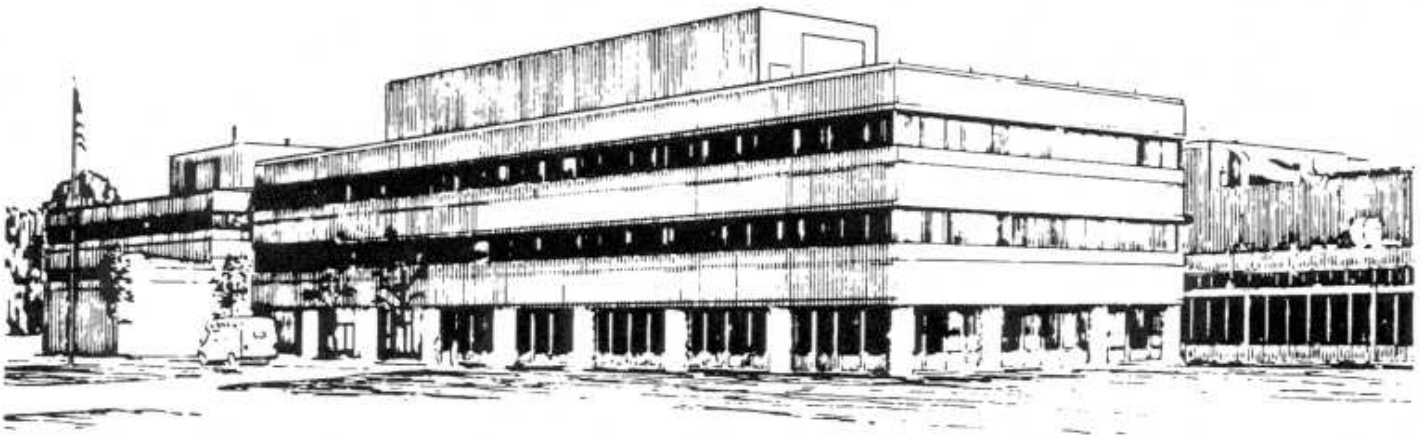

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NEUTRAL BEAM ION CONFINEMENT IN NSTX*

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Abstract

Neutral beam (NB) heating in the National Spherical Torus Experiment (NSTX) began in September 2000 using up to 5 MW of 80 keV D beams. An initial assessment of beam ion confinement has been made using neutron detectors, a neutral particle analyzer (NPA) and a Faraday cup beam ion loss probe. Preliminary neutron results indicate that confinement may be roughly classical in quiescent discharges, but the probe measurements do not match a classical loss model. MHD activity, especially reconnection events (REs) causes substantial disturbance of the beam ion population.

Introduction

A major goal of spherical tokamak (ST) research is to obtain plasmas at high beta (i.e. β_T>10%) via auxiliary heating. NB heating experiments in NSTX began in September 2000 using up to 5 MW of 80 keV D beams from three co-injecting beam sources with tangency radii of 69.4 cm, 59.2 cm, and 48.7 cm (designated A, B, & C, respectively). In order to obtain high beta efficiently in an ST, the NB ions must remain well confined as they slow down and heat the plasma. The purpose of this paper is to provide an initial assessment of the quality of NB ion confinement in quiescent NSTX plasmas and to describe some observations of beam ion loss due to magnetohydrodynamic (MHD) instabilities.

In order to characterize beam ion confinement in NSTX, several diagnostics are used. These include a neutral particle analyzer[1] (NPA) capable of looking at ions in both the thermal and suprathermal energy ranges, neutron detectors, and a Faraday cup based fast lost ion probe (FLIP). The NPA on NSTX utilizes a PPPL-designed E||B spectrometer which measures the energy spectra of H and D simultaneously with 39 energy channels per mass species and a time resolution of 1 msec. The neutron detectors on NSTX consist of both ^{235}U fission chambers and plastic scintillators. These give an absolutely-calibrated measure of the neutron emission from DD fusion reactions between NB ions and bulk plasma ions. The

FLIP diagnostic[2] measures the loss of ions with energies >1 keV. It is located on the outer wall of the vessel, at the midplane, and has apertures at R=1.61 m, 1.63 m, and 1.66 m.

Loss model results

NB ion loss fractions have been modeled with the EIGOL code[3], which follows the full gyro-orbits of particles but does not include the effects of collisions. The losses vary strongly with plasma current, being ~15% lost at the standard current of 1 MA, and increasing rapidly to ~40% at 0.5 MA. The loss fraction is relatively insensitive to plasma density, but does drop by a factor of three if the distance between the outer wall and the separatrix is increased from 5 to 15 cm. Simulations also show a significant variation in the confined fraction depending upon which of the three beam sources is used. For a representative 1 MA equilibrium, the loss fractions are 11% (A), 13% (B), and 19% (C). In addition, the loss fractions and neutron rates have been computed with the TRANSP code.

Confinement in quiescent plasmas

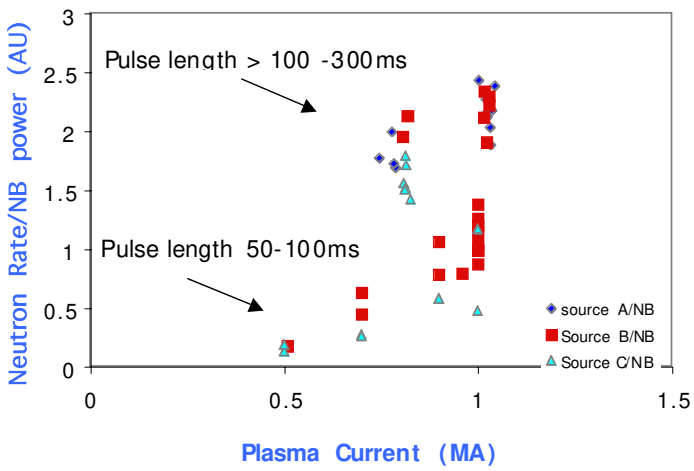

Figure 1: Neutron rate per unit neutral beam power as a function of plasma current for single NB source plasmas in NSTX. Better performance is seen as the current increases. In addition, sources A & B always produce more neutrons than source C.

Figure 1 shows the neutron rate as a function of plasma current and for beam lines of different tangency radii in NSTX. Two clusters of shots from two different campaigns are evident with distinctly different efficiencies of neutron production. Both data sets, however, show the trend of increasing neutron yield with increasing current, as expected if the NB ion confinement was improving with higher current. In addition, the data show that the neutron production from source C is distinctly lower than that from the other two sources (which are both about equally efficient). This is also in qualitative agreement with the predictions of the EIGOL code. In addition, the measured neutron rate agrees with that from TRANSP calculations, which include both orbit

loss and collisional effects, for the several shots that have been analyzed. Similarly, the neutron decay time after NB turn off usually matches that computed from the collisional slowing down of the NB ions, suggesting no large anomalous losses.

Measurements of the NB ion loss rate to the walls as a function of plasma current are depicted in Fig. 2. They display the expected increase in loss fraction with decreasing plasma current. However, power law fits to the data show distinctly different exponents from the same fits to the model ($I_p^{-1.80}$). A similar sort of variation is seen in the loss vs. R_{tan} of the beam source, but again the variation of the measured loss is much larger than that predicted. In addition, the absolute magnitude of the loss is about ten times smaller than expected from EIGOL and TRANSP simulation results.

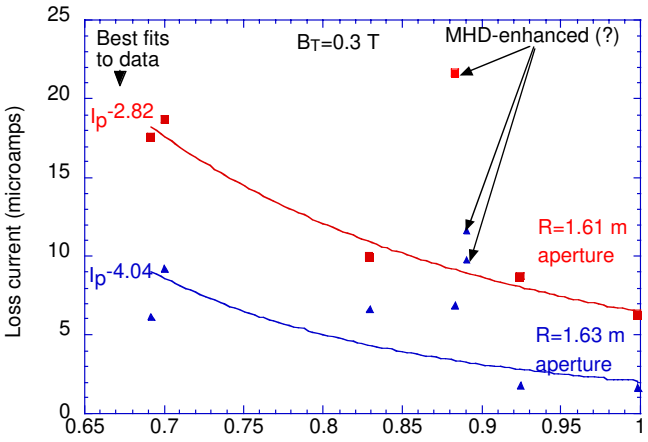

Figure 2: Measured beam ion loss currents at the NSTX midplane as a function of plasma current. Shown also are power law fits to the data and model results.

Our preliminary conclusion from the neutron measurements is that the loss of beam ions is consistent with the presence of only prompt orbit loss and collisional slowing down. Faraday cup loss measurements yield a more uncertain result as the loss levels are unexpectedly small and vary more strongly than the prompt loss model predicts. So, a more detailed and quantitative study is warranted.

MHD effects on confinement

An example of energetic ion behavior resulting from MHD activity is given in Fig. 3. Panel (d) shows a large n=2 mode arising at 0.26 sec followed by an additional n = 1 mode at 0.32 sec as determined from Mirnov coil measurements (b), which also shows that q(0) > 1 during this period. Onset of the n = 2 mode leads to a decay of the energetic ion population (E ~ 5 – 80 keV) and consequently the neutron yield as shown in panel (d). Thermal ions (E ~ 0.5 – 5 keV) are also lost during MHD activity producing a collapse in the ion temperature. The effect of RE activity (at the upticks in the plasma current in panel (a)) differs from that observed for MHD modes. In this case, prompt loss of the energetic ions occurs on a time

scale of ≤ 5 ms while the thermal ions remain confined but are redistributed outboard from the core to a region of higher neutral density which increases the neutral particle flux and apparent T_i measured by the NPA.

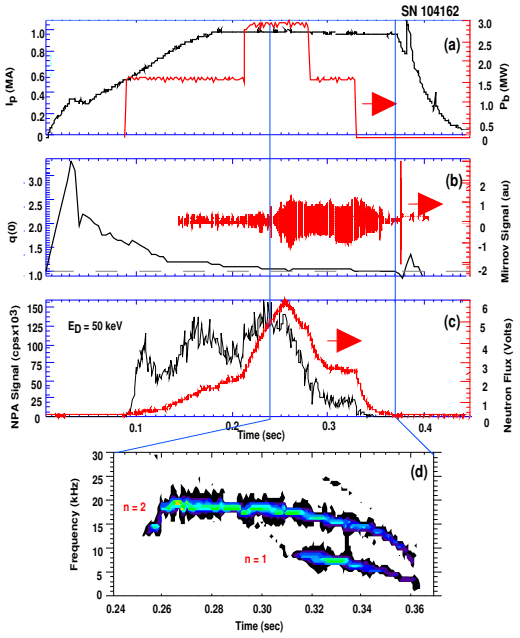

Figure 3: MHD activity (b & d) reduces neutron yield and energetic D ion confinement (c).

The neutron rate is observed to drop very rapidly when REs occur, indicating rapid loss of a large fraction of the NB ions. Simultaneously, the FLIP records large loss signals, starting a few ms before the plasma current spike. These, along with NPA data, indicate that REs can cause strong deconfinement of fast ions. Sawteeth crashes can also cause a substantial reduction in the neutron signal and cause large loss spikes on the FLIP. However, only a limited alteration of the NPA signal is seen.

Summary

An initial study of beam ion confinement in NSTX indicates that neutron rates produced by beam ions are generally consistent with those expected classically from prompt orbit loss and collisional slowing down. Some features of the beam ion loss measurement vs plasma current require further investigation to determine whether they can be reconciled with a classical ion loss model. MHD activity, especially REs, is observed to cause substantial redistribution and loss of beam ions in NSTX.

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2. D. S. Darrow, *et al., Rev. Sci. Instrum* . **72**, 784 (2001).
3. D. S. Darrow, *et al.,* in Proceedings of the 26th EPS Conference on Controlled Fusion and Plasma Physics, Maastricht, The Netherlands, 14-18 June 1999.

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