GA–A27790

FAST ION TRANSPORT DURING APPLIED 3D MAGNETIC PERTURBATIONS ON DIII-D

by
M.A. VAN ZEELAND, N.M. FERRARO, W.W. HEIDBRINK, G.J. KRAMER, D.C. PACE,
S.L. ALLEN, X. CHEN, T.E. EVANS, B.A. GRIERSON, M. GARCIA-MUNOZ,
J.M. HANSON, M.J. LANCTOT, L.L. LAO, C.J. LASNIER, R.A. MOYER,
R. NAZIKIAN, D.M. ORLOV, AND J.-K. PARK

APRIL 2014

GENERAL ATOMICS

DISCLAIMER

GA–A27790

FAST ION TRANSPORT DURING APPLIED 3D MAGNETIC PERTURBATIONS ON DIII-D

by

M.A. VAN ZEELAND, N.M. FERRARO, W.W. HEIDBRINK,* G.J. KRAMER,† D.C. PACE, S.L. ALLEN,‡ X. CHEN,¶ T.E. EVANS, B.A. GRIERSON,† M. GARCIA-MUNOZ,§ J.M. HANSON,# M.J. LANCTOT, L.L. LAO, C.J. LASNIER,‡ R.A. MOYER,△ R. NAZIKIAN,† D.M. ORLOV,△ AND J.-K. PARK†

This is a preprint of the synopsis for a paper to be presented at the Twenty-Fifth IAEA Fusion Energy Conf., October 13-18, 2014 in Saint Petersburg, Russia.

*University of California Irvine, Irvine, California.
†Princeton Plasma Physics Laboratory, Princeton, New Jersey.
‡Lawrence Livermore National Laboratory, Livermore, California.
¶Oak Ridge Institute for Science Education, Oak Ridge, Tennessee.
§Max-Planck-Institut für Plasmaphysik, Garching, Germany.
#Columbia University, New York, New York.
△University of California San Diego, La Jolla, California.

Work supported in part by
the U.S. Department of Energy under
DE-FC02-04ER54698, SC-G903402, DE-AC02-09CH11466,
DE-AC52-07NA27344, DE-AC05-06OR23100, DE-FG02-04ER54761,
and DE-FG02-08ER54984

GENERAL ATOMICS PROJECT 30200
APRIL 2014

GENERAL ATOMICS

Fast Ion Transport During Applied 3D Magnetic Perturbations on DIII-D

EX-W

M.A. Van Zeeland[1], N.M. Ferraro[1], WW. Heidbrink[2], G.J. Kramer[3], D.C. Pace[1], S.L. Allen[4], X. Chen[5], T.E. Evans[1], B.A. Grierson[3], M. Garcia-Munoz[6], J.M. Hanson[7], M.J. Lanctot[1], L.L. Lao[1], C.J. Lasnier[4], R.A. Moyer[8], R. Nazikian[3], D.M. Orlov[8], and J.-K. Park[3]

[1]General Atomics, PO Box 85608, San Diego, CA 92186-5608, USA
[2]University of California at Irvine, Irvine, CA 92697, USA
[3]Princeton Plasma Physics Laboratory, PO Box 451, Princeton, NJ 08543-0451, USA
[4]Lawrence Livermore National Laboratory, 7000 East Ave, Livermore, CA 94550, USA
[5]Oak Ridge Institute of Science Education, Oak Ridge, TN
[6]Max-Planck-Institut für Plasmaphysik, Euratom Association, Garching, Germany.
[7]Columbia University, 116th St and Broadway, New York, NY 10027, USA
[8]University of California San Diego, 9500 Gilman Dr., La Jolla, CA 92093-0417, USA
email: vanzeeland@fusion.gat.com

Pitch angle and energy resolved measurements as well as wide field-of-view infrared imaging show fast ion losses correlated with applied 3D fields in DIII-D plasmas [1] – modeling of these measurements gives confidence in our ability to predict this important effect in ITER and future devices. In DIII-D L-mode discharges with a slowly rotating n=2 magnetic perturbation, loss signals arising on separate scintillator detectors (FILDs) (Fig. 1), near and well below the plasma midplane, are observed to decay within one poloidal transit time after beam turn-off indicating they are predominantly prompt loss orbits. Full orbit modeling of these results including 3D perturbed beam ion birth profiles and scrape-off-layer ionization reproduces many features of the measured losses. Extension of the simulations to n=3 resonant magnetic perturbations (RMPs) edge localized mode (ELM) suppressed plasmas shows a significant impact on edge EP confinement which depends largely on the model for plasma response.

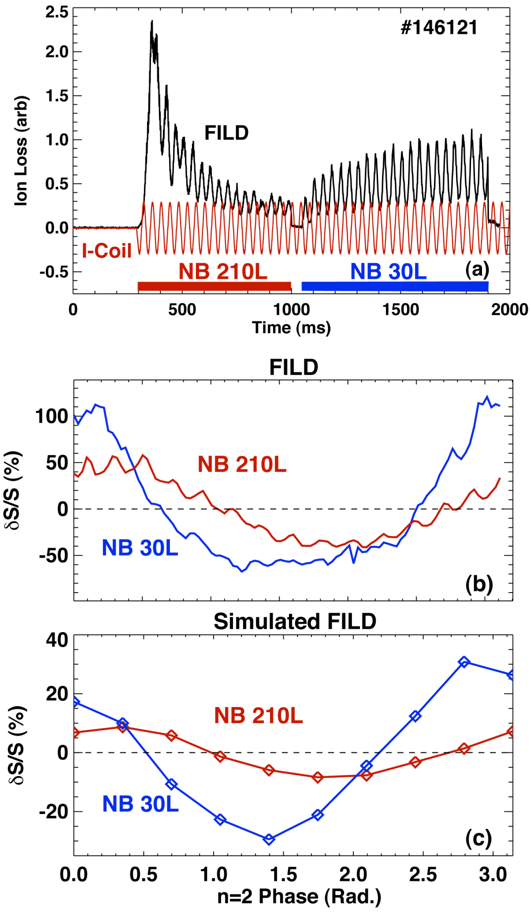

Fig. 1. DIII-D #146121. (a) FILD and n=2 I-coil timetraces. (b) FILD data from 30L (blue) and 210L (red) mapped to equivalent phase of the n=2 perturbation. Data from 40 ms interval centered at t = 965 ms (210L) and t = 1070 ms (30L) (c) Simulation results for expected modulation.

Beam ion losses due to applied n=2 fields in a DIII-D L-mode plasma are shown in Fig. 1(a,b) and are well matched by simulations results in Fig. 1(c) from beam deposition and full orbit modeling utilizing M3D-C1 [2] calculations of the perturbed kinetic profiles and fields. The predicted phase of the modulated loss signal with respect to the I-coil currents is in close agreement with FILD measurements as is the relative amplitudes of the modulated losses for the co- and counter-current beam used in the experiment.

Modulation of the edge density profile with rotation of the n=2 fields as calculated by M3D-C1 is consistent with Thomson and bremsstrahlung measurements, and results in a modification to the beam ion birth profile. The dominant factor causing modulation of the losses to the fast ion loss detectors, however, is found to be the perturbed magnetic field. Calculations indicate total prompt loss to the DIII-D wall increases with application of the n=2 perturbation by up to ~7% for co-current injected beams and ~3% for counter-current injected beams, depending on phase of the perturbation relative to the injected beam.

Full-orbit simulations show that resonances with the applied perturbation can occur for fast ions in these plasmas, leading to large changes in toroidal canonical angular momentum for localized regions of phase space – something which could potentially be used as an EP control tool to selectively modify the drive for various EP instabilities. While select regions of phase space can be altered significantly, SPIRAL [3] simulations that follow full energy beam ions throughout the scattering/ slowing down process in the presence of the applied fields show relatively small changes in the resulting confined distribution for these L-mode plasmas.

Similar slowing-down time-scale full-orbit simulations for an n=3 RMP ELM suppressed plasma show that the applied fields induce a large loss of fast ions (10%–20% of injection rate for half-energy beam ions) from the edge of the plasma and that the magnitude of the loss depends significantly on the model of the perturbed magnetic field (Fig. 2); a comparison to edge FIDA data is underway. Calculations including the plasma response to the non-axisymmetric fields show up to a factor of two enhancement of the losses relative to those with vacuum n=3 fields alone. In the first comparison of its type, the largest predicted losses are found using fields from the Ideal Perturbed Equilibrium Code (IPEC) [4] followed by the two fluid resistive MHD code M3D-C1 [2]. To explore the role of the plasma response further, the "light ion beam probe" technique, which exploits prompt loss orbits as a probe of internal fields, has been utilized in a series of discharges with varying beta and a change in 3D field induced beam ion losses has been observed correlated with edge magnetic probe measured response.

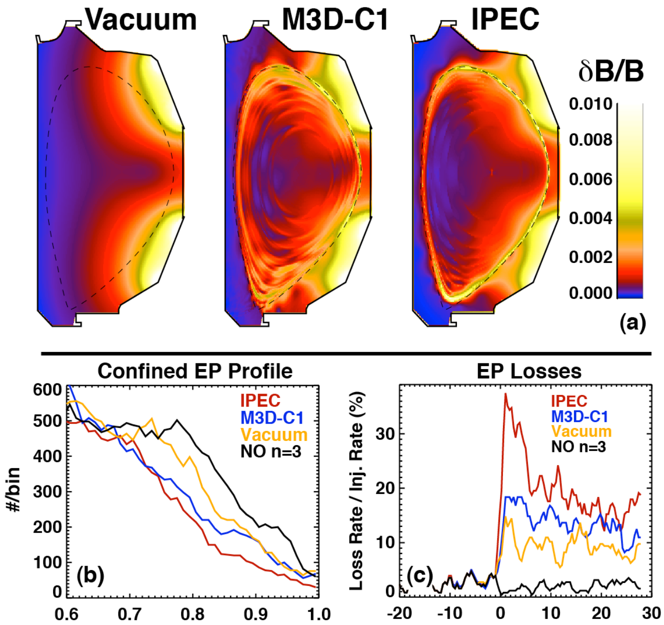

Fig. 2. (a) Amplitude of perturbed n=3 fields from Vacuum, M3D-C1, and IPEC. (b) Radially binned half energy (~40 keV) injected beam ions at t = 30 ms. (c) Total loss rate of half energy injected beam ions vs time. I-coil turns on at t = 0 ms in simulation.

Applied 3D fields are observed to cause loss of fast ions in DIII-D experiments and comparisons to modeling give confidence in our ability to predict this effect. Simulations also indicate a significant redistribution/loss of fast ions occurs n=3 RMP ELM suppressed plasmas and comparisons to experiment are underway.

This work was supported in part by the US Department of Energy under DE-FC02-04ER54698, SC-G903402, DE-AC02-09CH11466, DE-AC52-07NA27344, DE-AC05-06OR23100, DE-FG02-04ER54761, and DE-FG02-07ER54917.

[1] M A Van Zeeland, et al., Plasma Phys. Control. Fusion **56**, 015009 (2014)
[2[N.M. Ferraro and S.C. Jardin, J. Comput. Phys. **228**, 7742 (2009)
[3] G.J. Kramer, et al., Plasma Phys. Control. Fusion **55**, 025013 (2013)
[4] Jong-kyu Park, et al., Phys. Plasmas **14**, 052110 (2007)