GA–A27247

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APRIL 2012

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This is a preprint of the synopsis for a paper to be presented at the Twenty-fourth IAEA Fusion Energy Conf., October 8-13, 2012 in San Diego, California.

*University of California San Diego, La Jolla, California, USA.
†Lawrence Livermore National Laboratory, Livermore, California, USA.

Work supported in part by
the U.S. Department of Energy
under DE-FG02-95ER54309, DE-FC02-04ER54698, DE-FG02-07ER54917,
and DE-AC52-07NA27344

GENERAL ATOMICS PROJECT 03726
APRIL 2012

Edge Plasma Response to Non-Axisymmetric Fields in Tokamaks TH-D

N.M. Ferraro[1], L.L. Lao[1], R.A. Moyer[2], D.M. Orlov[2], R.J. Buttery[1], T.E. Evans[1], M.J. Lanctot[3], P.B. Snyder[1], and M.R. Wade[1]
e-mail: ferraro@fusion.gat.com

[1]General Atomics, P.O. Box 85608, San Diego, California 92186-5608, USA
[2]University of California San Diego, La Jolla, California 92093-0417, USA
[3]Lawrence Livermore National Laboratory, Livermore, California 94550, USA.

Recent advances in modeling capabilities offer significant improvements in calculating tokamak response to applied non-axisymmetric magnetic fields. These new capabilities are employed to understand and interpret the substantial effects that non-axisymmetric fields are observed to have on transport and stability, which include dramatic changes in rotation and particle transport, tearing mode stability [1], and the partial or complete suppression of edge-localized modes (ELMs) under some circumstances [2]. Given the potential impact of these effects on the performance of future tokamak designs including ITER — both positive and negative — it is important to develop and validate the capability to model these effects predictively. A major obstacle to obtaining such a capability is the significant and complex magnetic response of the plasma to applied fields. Here we describe recent advances in developing and validating methods to calculate this response. Calculations using a resistive two-fluid model in diverted toroidal geometry confirm the special role of the perpendicular electron velocity in suppressing the formation of islands in the plasma (Fig. 1). The possibility that pedestal width is constrained by the formation of an island chain near the top of the pedestal, where the zero-crossing of the perpendicular electron velocity may coincide with a mode-rational surface, is explored, with a focus on the implications for ELM suppression. Modeling results are compared with empirical data where possible. It is shown that modeling is successful in reproducing some experimentally observed effects of applied non-axisymmetric fields on the edge temperature and density profiles.

The model used in these calculations [3] goes beyond models that have been employed for this purpose previously [4-6] in several ways. First, the model is fully compressible and does not use a "reduced" set of equations. Second, realistic diverted toroidal geometry is

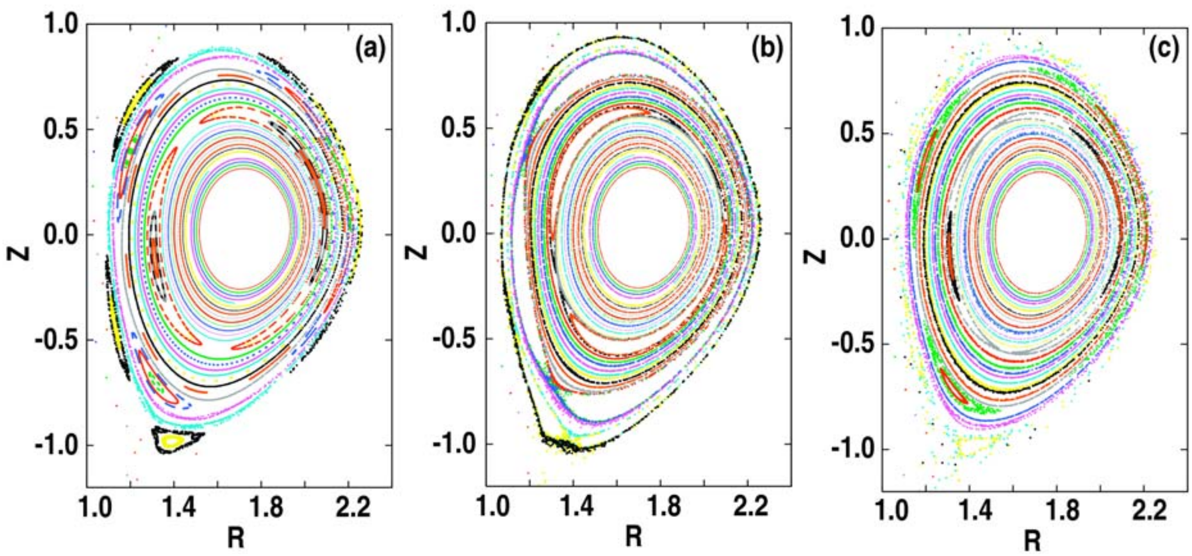

Fig. 1. Poincaré plots showing the magnetic field structure given a 5 kA n=1 I-coil perturbation with (a) no plasma response; (b) a non-rotating plasma; and (c) a rapidly rotating plasma with a strongly sheared edge rotation profile.

used, and therefore poloidal Fourier modes are properly coupled. Third, the computational domain includes the plasma, the separatrix, and the scrape-off layer self-consistently. The scrape-off layer is treated resistively, which allows the formation of halo currents. Finally, two-fluid terms are included self-consistently, which allows for the proper treatment of diamagnetic effects and distinct ion and electron velocities. This can be especially significant in the edge, where large pressure gradients can lead to substantial differences between the ion and electron velocities. The finite-element code M3D-C1 [7] is used to solve the model equations. This code employs an anisotropic, unstructured mesh and parallel sparse matrix solvers to allow the efficient solution of the time-independent response. Both linear and nonlinear models are considered.

Our results confirm and extend the predictions of analytic theory to realistic parameters and geometries. In two-fluid theory, the tearing response is expected to be most easily excited when the applied perturbation is static in the frame of the electrons. Our two-fluid modeling supports this conclusion, with the result that islands are opened most strongly excited by static fields where the electron velocity vanishes [3]. An unexpected finding is that strongly sheared edge rotation may bring stable edge-localized modes closer to marginal stability, potentially leading to stochastization in the edge (Fig. 1). For typical parameters, however, it is found that even when vacuum modeling suggests a fully stochastic field in the edge, KAM surfaces remain intact in the edge when the plasma response is taken into account, thereby limiting the predicted parallel thermal losses.

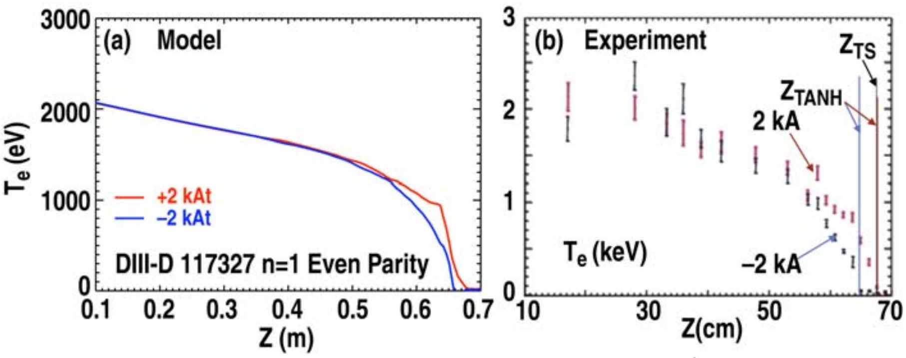

Fig. 2. Numerical modeling (a) recovers the ~2 cm shift in the electron temperature pedestal profile observed in experiments (b) when non-axisymmetric fields are applied. In this case, the temperature is measured with a ±2 kA *n*=1 perturbation in DIII-D shot 117327.

Modeling that includes the kink response of the plasma can reproduce experimentally observed shifts in edge density and temperature profiles. These shifts are often consistent with a rigid displacement of the plasma by up to a few centimeters – much larger than can be accounted for by vacuum modeling. An example of such a comparison with Thomson scattering data is illustrated in Fig. 2, in which a rotating *n*=1 is applied; *n*=2–4 cases are considered as well. Simulation results also compare favorably with beam emission spectroscopy data. It is shown that the observed shifts are due mainly to non-axisymmetric plasma displacements, as opposed to axisymmetric transport changes, or parallel thermal conductivity along stochastic field lines. These comparisons provide direct evidence that models are accurately capturing salient features of the actual plasma response.

This work was supported by the US Department of Energy under DE-FG02-95ER54309, DE-FC02-04ER54698, DE-FG02-07ER54917, and DE-AC52-07NA27344.

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