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RMP ENHANCED TRANSPORT AND ROTATION SCREENING IN DIII-D SIMULATIONS

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T.H. OSBORNE, L.L. LAO, and P.B. SNYDER,

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

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RMP Enhanced Transport and Rotational Screening in DIII-D Simulations TH-S

V.A. Izzo,[1] I. Joseph,[1] R.A. Moyer,[1] T.E. Evans,[2] M.E. Fenstermacher,[3] T.H. Osborne,[2] L.L. Lao,[2] and P.B. Snyder[2]

[1]University of California, San Diego, California 92093, USA
[2]General Atomics, San Diego, California 92186, USA
[3]Lawrence Livermore National Laboratory, Livermore, California 94550, USA

Simulations of DIII-D equilibria with applied non-symmetric perturbations have been performed with the magnetohydrodynamic (MHD) code NIMROD to investigate the transport effects of the applied fields. DIII-D experiments with applied resonant magnetic perturbations (RMP) have suppressed edge localized modes (ELMs) at low collisionality, primarily due to a reduction of the pedestal density [1]. The mechanism of the enhanced particle transport, without a significant pedestal temperature reduction, is the primary subject of investigation with NIMROD. These simulations support E×B convection as the operative mechanism.

In the absence of toroidal rotation, the simulated response of the plasma is to amplify the resonant components of the applied error field (Fig. 1), which is theoretically predicted [2] for tearing stable plasmas with the tearing stability parameter $\Delta' > -2m$ (where m is the poloidal mode number). The simulations begin with an EFIT reconstructed DIII-D equilibrium, and impose the vacuum n = 1, 2, and 3 components of the fields generated by the DIII-D I-coils, C-coils, and the measured intrinsic error fields. The I-coil RMP fields have predominantly n=3 symmetry. The simulation boundary is placed outside the separatrix to include a vacuum region, and the boundary conditions effectively maintain constant coil currents as the plasma responds to and alters the applied vacuum fields inside the simulation domain. The resonant amplification factor varies with m, but is in the range of 2-5. The non-resonant components are unaffected by the plasma response. The n=0 and n=3 components of the plasma kinetic energy grow as the plasma responds to the applied fields, and are dominant as the magnetic configuration reaches approximate steady state.

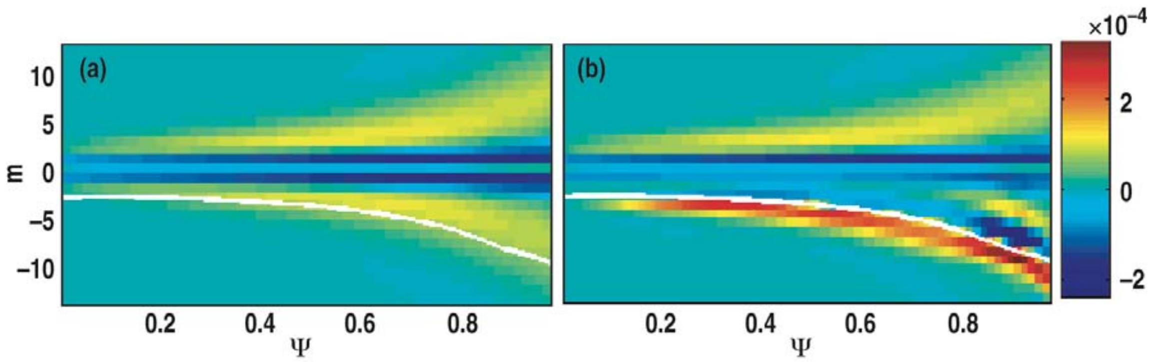

Fig 1. (a) The normal (to the flux surface) component of the vacuum n=3 magnetic fields (T) applied as the initial condition for the NIMROD simulations — plotted as a function of the normalized poloidal flux Ψ and the poloidal mode number, m. The superimposed white line is the resonant line m = -3q. (b) The n=3 normal magnetic field spectrum of the steady state solution obtained by NIMROD after the resonant mode amplification by the plasma.

The growth of the n=3 plasma kinetic energy during the plasma response is characterized by the formation of poloidal E×B convection cells crossing the separatrix [Fig. 2(a)]. These convection cells have the effect of pushing particles from the pedestal into the vacuum region. Two additional simulations include toroidal rotation; the core rotation is about 100 km/s in each case, dropping to about 1 km/s at the separatrix in one case, and 35 km/s in the other case. The E×B convection mechanism is not strongly affected by the lower separatrix rotation, although a reduction of the resonant field amplitude is observed. At the higher separatrix rotation, the velocity of the poloidal convection cells is reduced by about half, but the enhanced particle transport is entirely eliminated, suggesting a possible secondary effect of the rotation on transport beyond the screening effect on the applied fields. The initial and final density profiles for the three simulations with varying rotation are seen in Fig. 2(b).

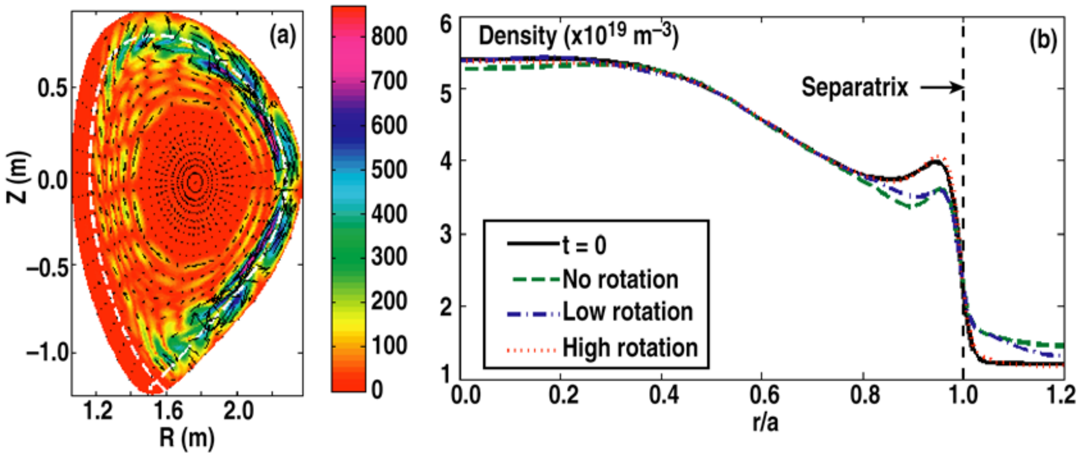

Fig. 2. (a) The n=3 poloidal velocity (m/s) in the simulation without rotation. Convection cells crossing the separatrix form on the outboard side. (b) The initial density profile, and final density profiles for simulations with three values of rotation at the separatrix. At no or low rotation, density is pumped out. The magnetic fields are nearly steady state in each case, but the transport time scales are longer, so that the density profile is still slowly evolving.

The anticipated resonant mode amplification in the dimensionless parameter regime of ITER is assessed using NIMROD scaling studies in conjunction with analytic theory. The resonant mode amplification that produces E×B convection cells is an ideal plasma response, not directly dependent on plasma resistivity or toroidal rotation. However, the rotational screening of the applied RMP increases with rotation and decreases with resistivity. If E×B convection is the operative mechanism on DIII-D, then the lower rotation and lower resistivity of ITER plasmas have opposing effects on the efficacy of this mechanism in ITER. In fact, regardless of the density transport mechanism, the largest ratio of the resonant fields to the undesirable non-resonant components should clearly be sought, and a vacuum field calculation is insufficient.

Further simulations investigate the effects of varying 1) the initial equilibrium (particularly its stability properties), and 2) the energy transport model used in NIMROD (to reproduce the temperature gradient increase often observed in DIII-D). Finally, a DIII-D experiment performed with time varying n=1 I-coils fields is simulated as a simple benchmarking test of the computed NIMROD plasma response to the applied fields.

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