GA–A27783

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APRIL 2014

GENERAL ATOMICS

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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.

*Oak Ridge National Laboratory, Oak Ridge, Tennessee.
†University of Texas at Austin, Austin, Texas.
‡Princeton Plasma Physics Laboratory, Princeton, New Jersey.

Work supported by
the U.S. Department of Energy
under DE-AC05-00OR22725, DE-FC02-04ER54698,
DE-FG03-97ER54415, and DE-AC02-09CH11466

GENERAL ATOMICS PROJECT 30200
APRIL 2014

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Measuring Islands and Plasma Response to Applied 3D Fields EX-S

M.W. Shafer[1], E.A. Unterberg[1], A. Wingen[1], T.E. Evans[2], N.M. Ferraro[2], M.E. Austin[3], D.J. Battaglia[4], J.M. Canik[1], J.H. Harris[1], D.L. Hillis[1], S.P. Hirshman[1], J.D. Lore[1]

[1]Oak Ridge National Laboratory, PO Box 2008, Oak Ridge, TN 37831, USA
[2]General Atomics, PO Box 85608, San Diego, CA 92186-5608, USA
[3]University of Texas-Austin, Austin, TX 78712-1047, USA
[4]Princeton Plasma Physics Laboratory, PO Box 451, Princeton, NJ 08543-0451, USA
email: shafermw@ornl.gov

Recent experimental observations on DIII-D have advanced the understanding of plasma response to resonant magnetic perturbations (RMPs) in both L-mode and H-mode plasmas. In L-mode plasmas, fine torque scans reveal that large RMP-induced islands are present at multiple mode-rational surfaces at low rotation, but are completely screened at higher rotation. The steep-gradient region of the H-mode pedestal, which is characterized by high perpendicular electron rotation, $\omega_{e,\perp}$, does not show clear evidence of islands. Instead, an m~11 helical kink-like perturbation is observed here. These measurements are compared to vacuum and extended MHD response models to validate their applicability and predictive capability. In general, these measurements show the importance of the modification from vacuum modeling by extended MHD in describing the plasma response to 3D fields.

Torque scans using mixtures of co- and counter-current neutral beam injection were performed on low magnetic shear, inner wall limited, L-mode discharges during the application of n=1 RMPs. At sufficiently low torque (<0.3 N-m), the fields penetrate and form n=1 island chains at m=2,3,4. There is an observed nonlinear threshold for this torque, where small torque increments lead to a completely screened plasma response. Initial analysis indicates that near-zero $\omega_{e,\perp}$ is found not to be a sufficient condition for island formation, as it is observed to be approximately zero in cases where RMPs are completely screened.

The internal island response to the n=1 perturbations is seen via strong T_e flattening at each mode-rational surface. This is shown in Fig. 1(a) for the Thomson scattering measured T_e of the low-torque discharge (~0.3 N-m). Grey bars indicate the flattened width. The ECE-measured T_e, shown in Fig. 1(a), is from the same discharge but samples the X-point of the island chains. Also shown is the Thomson-measured profile from the higher-torque

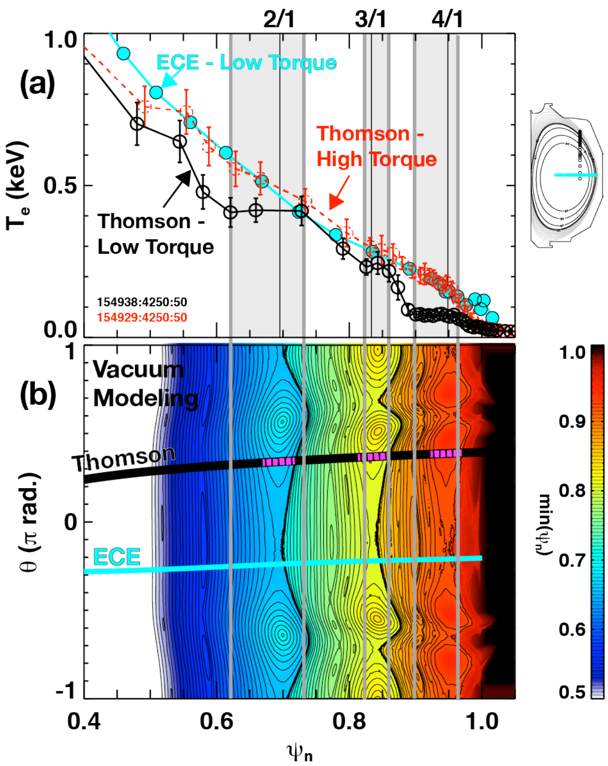

Fig. 1. (a) Temperature profiles for low-torque discharge in black open circles (Thomson) and cyan filled circles (ECE); high-torque discharge in dashed red circles (Thomson). (b) Vacuum field penetration with Thomson and ECE view paths. Dashed magenta lines indicate the Thomson sampling region of the n=1 islands.

discharge (~0.4 N-m) that has the same amplitude and RMP phase applied but remains free of islands. The ECE X-point profile matches well to the screened profile, which indicates little stochasticity and likely nested island flux surfaces. Furthermore, the presence of islands allows for an enhanced T_e gradient between islands, specifically between the 4/1 and 3/1 islands, possibly due to the compression of magnetic flux between the islands.

Vacuum predictions of the n=1 perturbation are shown in Fig. 1(b). This image shows the field penetration described by the minimum value in ψ_n from a field line launched at each (ψ_n,ϑ) point using the MAFOT code [1]. Solid horizontal lines illustrate the viewing geometry in (ψ_n,ϑ) space for the Thomson and ECE diagnostics. Here, the ECE diagnostic is shown to sample the island X-point, whereas the Thomson diagnostic passes close to the O-points of each of the n=1 islands. Dashed lines indicate the vacuum predicted Thomson island width. Vertical bars indicate the estimated width from the flattened profiles, showing the amplification from vacuum for the 2/1 and 4/1 surfaces. Linear simulations using the two-fluid resistive MHD code, M3D-C1 [2], likewise predict amplified islands for this equilibrium. The linear simulations do not capture the correct width nor the torque threshold for island formation; simulations of the higher torque discharge also show amplified islands. This effect is not unexpected as island formation and saturation are both nonlinear processes. Nonlinear MHD calculations are underway.

In diverted, H-mode discharges with n=3 RMP's applied, tangential soft x-ray (SXR) imaging of the X-point region shows a helical, kink-like perturbation. This perturbation is isolated by alternating the n=3 toroidal phase and subtracting the phase-locked image. A line-of-sight inversion using Tikhonov regularization is used to create a local estimate of the perturbed structure and is shown in Fig. 2(a). Linear two-fluid resistive MHD simulations show a similar kink perturbation, shown in Fig. 2(b). Here, the two-fluid response has been forward-modeled using synthetic diagnostics to directly compare to the SXR camera data. The modeled response results from both a high $\omega_{e,\perp}$ and edge current that lead to a screening and kinking effect, respectively. The measured perturbation corresponds better to the two-fluid modeling than the highly stochastic vacuum response (not shown). This indicates that the measured perturbation is likely a result of high screening due to the large $\omega_{e,\perp}$ and also a driven kink mode destabilized by the bootstrap current. Outside of this steep gradient region, vacuum modeling does well to describe imaging measurements that show lobes extending from the separatrix where resistivity is high and rotation is small [3]. In summary, these results show that vacuum-based modeling works in limited regions, but otherwise extended MHD is needed to describe measured internal responses to applied 3D fields.

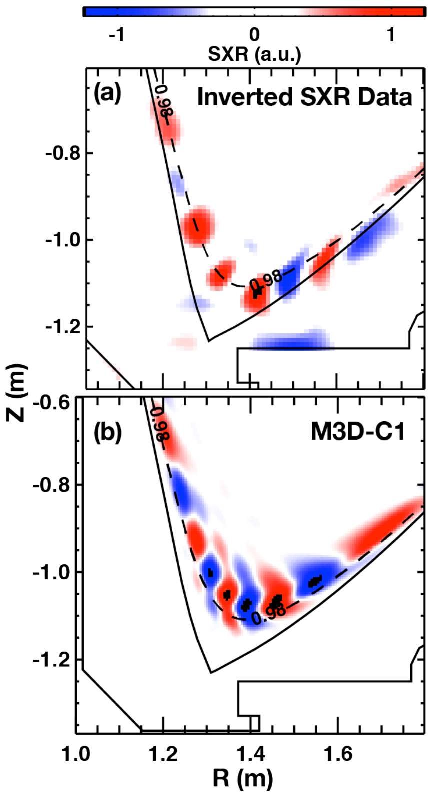

Fig. 2. (a) Measured SXR perturbation; (b) Forward-modeled synthetic SXR perturbation from the M3D-C1 code.

This work was supported by the US DOE under DE-AC05-00OR22725, DE-FC02-08ER54977, DE-FG03-97ER54415, and DE-AC02-09CH11466.

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