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EXPERIMENTAL STUDY OF FAST WAVE ABSORPTION MECHANISMS IN DIII-D IN THE PRESENCE OF ENERGETIC IONS

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R.I. PINSKER, M. PORKOLAB,* W.W. HEIDBRINK,† Y. LUO,† C.C. PETTY, R. PRATER,
M. CHOI, F.W. BAITY,‡ J.C. HOSEA,§ R.W. HARVEY,¶ A.P. SMIRNOV,¶ E.F. JAEGER,‡
and M. MURAKAMI‡

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*Massachusetts Institute of Technology, Cambridge, Massachusetts.
†University of California-Irvine, Irvine, California.
‡Oak Ridge National Laboratory, Oak Ridge, Tennessee.
§Princeton Plasma Physics Laboratory, Princeton, New Jersey.
¶CompX, Del Mar, California.

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Experimental Study of Fast Wave Absorption Mechanisms in DIII-D in the Presence of Energetic Ions

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R.I. Pinsker,[1] M. Porkolab,[2] W.W. Heidbrink,[3] Y. Luo,[3] C.C. Petty,[1] R. Prater,[1] M. Choi,[1] F.W. Baity,[4] J.C. Hosea,[5] R.W. Harvey,[6] A.P. Smirnov,[6] E.F. Jaeger,[4] and M. Murakami[4]

[1]General Atomics, P.O. Box 85608, San Diego, California 92186-5608, USA
[2]Massachusetts Institute of Technology, Cambridge, Massachusetts, USA
[3]University of California-Irvine, Irvine, California, USA
[4]Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA
[5]Princeton Plasma Physics Laboratory, Princeton, New Jersey, USA
[6]CompX, Del Mar, California, USA

Experiments on DIII-D have shown that fast Alfvén waves (FWs) can be damped on core electrons with minimal damping on fast ions at high harmonics, in contrast to early code predictions of strong fast ion absorption; these differences may result from known edge losses not yet included in the modeling. Fast wave current drive (FWCD) is an important option for central current drive in ITER, especially in view of the difficulty of achieving sufficiently high energy and power in negative-ion-based neutral beams for this application. Since ITER and any future fusion reactor will necessarily have large fast ion populations (alphas and perhaps injected ion species), it is important to have a validated quantitative model of the interaction between fast ions and FWs to assess the application of FWs for central heating and current drive. For FWCD, in which the intended absorption mechanism is Landau damping on electrons, absorption by ion cyclotron harmonic damping would reduce the available power to the electrons for heating and current drive. These DIII-D experiments have studied interaction between injected 80 keV deuterons and FWs at 60 MHz, 90 MHz, and at 116 MHz, at ion cyclotron harmonic numbers between 4 and 8.

While strong absorption of FWs at the 4th harmonic on injected deuterons has been clearly observed, ion absorption under the same conditions at 6th and 8th harmonics is seen to be weak. An experiment was performed in which 1.6 MW of FW power at 116 MHz (8th harmonic near the magnetic axis) was coupled to an L-mode discharge with 5 MW of 80 keV deuterium neutral beam injection; later in the same discharge, the effect of 0.8 MW of FW power at 60 MHz (4th harmonic near the magnetic axis) was compared with that of the 8th harmonic power. The effect of the FW was isolated by comparing this discharge with an otherwise identical discharge with no FW power. These comparisons are shown in Fig. 1, where differences in the plasma stored energy and in fusion neutron rate between the discharges with and without FW power is shaded. It is evident from the fusion neutron rate that the acceleration of beam ions by the FW is much stronger for the 4th harmonic case than for the 8th.

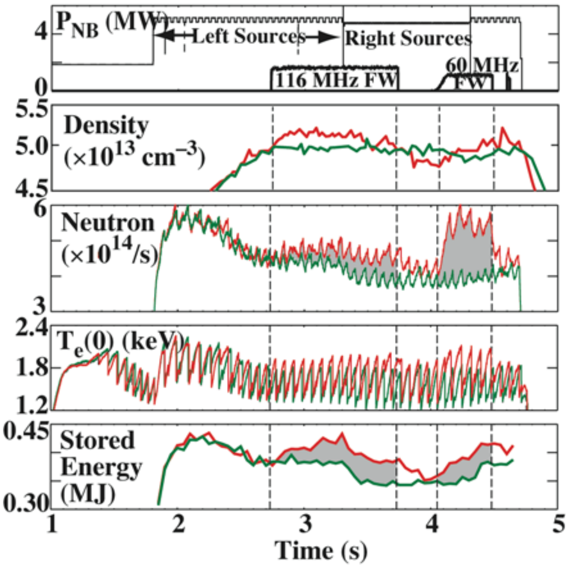

Fig. 1. Time history of high density L-mode discharge comparing 4th (60 MHz) and 8th harmonic (116 MHz) FW heating at 1.85 T. Dotted vertical lines show rf on and off times. Green traces from comparison case with no FW.

In these experiments, the FW/fast ion interaction was measured directly using the fast ion D_α (FIDA) spectroscopy diagnostic technique [1], which involves vertically-viewed D_α charge exchange recombination emission from one of the injected beams. This diagnostic confirmed that the absorption of the

FW power at the 4th harmonic accelerates deuterons near the injection energy, with a 65% enhancement of the signal in the 60-80 keV range, and accelerates particles to higher energy than the injection energy. The density of accelerated ions observed with this instrument is correlated with the enhanced fusion neutron emission rate. FIDA confirmed that the interaction at the 8th harmonic is much weaker than at the 4th (with identical plasma density, magnetic field, beam energy and power).

Sixth harmonic absorption on fast ions is also weak by comparison with that at the 4th harmonic at the same toroidal field. Experiments performed in 2007 compared 6th harmonic absorption of up to 2 MW of 90 MHz FW power with 4th harmonic absorption of 60 MHz FWs. At the lowest plasma density studied, the FIDA diagnostic observed weak beam acceleration in the 6th harmonic case compared with that observed in the 4th harmonic case. At higher density, no beam acceleration was observed in the 6th harmonic case and only electron damping was found. Confinement analysis supports the FIDA data, in that the 4th harmonic case shows the effect of a large fast ion population, which is not seen in the 6th harmonic cases. The direct electron damping of the FWs in the 6th harmonic case is weaker in the higher density case (lower electron temperature) compared with the lower density, and the global absorption is correlated with the single-pass absorption in this regime. This correlation suggests that a significant edge loss competes with the core absorption, as had previously been established in DIII-D FWCD experiments.

Competition between absorption on fast deuterons and on (initially) thermal protons at half the harmonic number was studied in mixed hydrogen/deuterium plasmas with deuterium beam injection. At high hydrogen fraction [H/(H+D)~25%], strong absorption on the thermal protons at 2nd harmonic prevents significant absorption on the fast deuterons. Hydrogen absorption is minimized in another experiment in which the 5th harmonic layer of deuterium passes through the magnetic axis so no hydrogen harmonic is present near the axis. Strong deuterium acceleration is observed from the FIDA diagnostic and from the fusion neutrons.

To date, simulation results do not fully agree with the experiment. These experiments have been modeled with the combination of the AORSA full-wave code and the CQL3D bounce-averaged Fokker-Planck code, CQL3D combined with the GENRAY ray-tracing model, and the ORBIT-RF Monte Carlo code combined with the TORIC full-wave model. So far these models are not fully in agreement with each other; semi-quantitative agreement with the experimental results is obtained in some cases. The experiments clearly show the importance of FW edge losses. Loss mechanisms such as sheath rectification, parametric decay instabilities, surface wave excitation, etc., which compete with core absorption in the experiment are not yet included in the modeling. In cases in which the edge losses per bounce and the core absorption per transit are comparable, the level of edge losses would strongly affect the FW amplitude in the core of the plasma. Since that FW amplitude is crucial in a quasilinear or nonlinear model, efforts are ongoing to assess the importance of various edge loss mechanisms in resolving the remaining discrepancies between the predictions of the models and the experimental results. Modeling the competition between direct electron absorption in the core, fast ion absorption in the core and edge losses is simpler in a ray-tracing approach, so the CQL3D/GENRAY approach is being used to study the partitioning of wave energy between these absorption channels. Incorporation of an edge loss model in the full-wave approach is ongoing.

Core absorption mechanisms will be much stronger in ITER, so that edge losses should be much less significant than in DIII-D, but the competition between core damping mechanisms will be similar. Hence, establishment of an experimentally benchmarked quantitative model of the partitioning of FW power among competing absorption processes is important in both cases.

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[1] W.W. Heidbrink, *et al.*, Plasma Phys. Control. Fusion **49**, 1457 (2007).