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Authors

Fisher, RK
Boivin, RL
Garcia-Munoz, M
et al.

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Fast Ion Loss Diagnostics on DIII-D

R.K. Fisher[a], R.L. Boivin[a], M. Garcia-Munoz[b], W.W. Heidbrink[c], D.C. Pace[c],
M.A. Van Zeeland[a], and Y.B. Zhu[c]

[a]*General Atomics, PO Box 85608, San Diego, California 92186-9784, USA*
[b]*Max-Planck-Institut fur Plasmaphysik, Garching, Germany*
[c]*University of California-Irvine, Irvine, California, USA*

New fluctuation and fast ion diagnostics on DIII-D have resulted in the first experimental measurements of the spatial structure of Alfvén eigenmodes (AEs) and their impact on the radial profile of confined beam ions. This paper describes fast ion loss diagnostics designed to help understand how AE's and other instabilities perturb the fast ion orbits and degrade their confinement.

Introduction

Fast ions from neutral beam injection, ion cyclotron heating, and fusion reactions play a fundamental role in the heating and stability of tokamak plasmas. Sawteeth and tearing modes affect fast ion confinement, while large fast ion densities can drive collective instabilities, including toroidicity-induced Alfvén eigenmodes. The effects of MHD activity on fast ions can significantly impact the plasma performance. Losses of energetic alpha particles from DT fusion in ITER will reduce the alpha heating available to reach ignition, and have the potential to cause major damage to the first wall.

Measurements of the internal mode structures of the fast ion induced instabilities inside the DIII-D plasma are based on beam emission spectroscopy (BES), far infrared (FIR) scattering, reflectometry, CO_2 interferometry, electron cyclotron emission (ECE), and magnetic fluctuation measurements [1]. Measured profiles of the confined beam ions in DIII-D using the recently developed fast ion D_α spectroscopy (FIDA) [2] show that instabilities redistribute fast ions radially outward.

Initial Results Using Faraday Collectors

Thin foil Faraday collectors near the midplane of DIII-D are used to measure fast ion losses [3]. These detectors are mounted inside a port box as shown in Fig. 1 and recessed 1.9 cm behind the first wall tiles. Modulation of the neutral beam sources has allowed observation of the prompt losses from each of the beam lines. The prompt losses are usually larger when the plasma current or toroidal field are low, likely a result of the larger drift orbits and gyroradii.

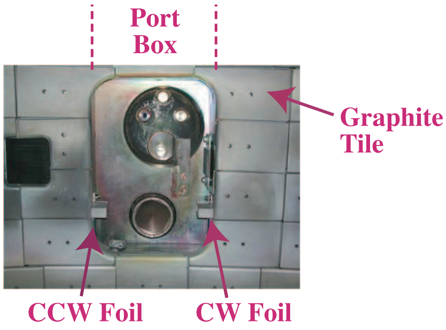

Fig. 1. Foil Faraday collectors mounted inside midplane port box.

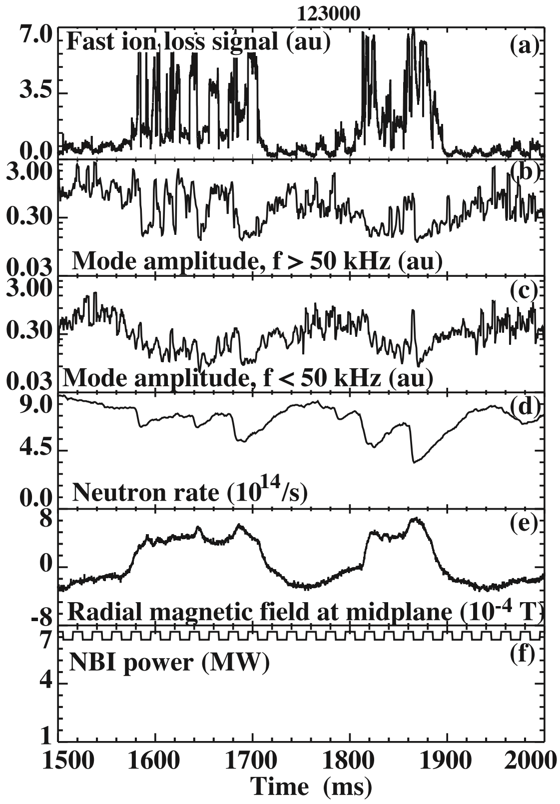

Fig. 2. A strongly driven discharge with toridicity-induced TAE and RSAE activity.

Plasma instabilities that result in magnetic field perturbations often produce enhanced fast-ion losses. MHD activity in the plasma core appears less effective in producing large fast ion losses than instabilities that cause large edge perturbations, such as edge harmonic oscillations. Often the largest losses are observed in plasmas with both edge and core oscillations, perhaps as a result of the core instability transporting fast ions to the portion of phase space that is depopulated by the edge instability. Enhanced losses often occur in discharges with beam-driven AE activity. Large losses occur during the phase of the discharge with strong activity, but the temporal correlation with the core AE mode amplitude is weak. Figure 2 shows a strongly driven discharge with both toridicity-induced Alfvén eigenmode (TAE) and reversed-shear Alfvén eigenmode (RSAE) activity. The losses appear to correlate more with the low-frequency radial magnetic field near the plasma edge rather than the high frequency AE activity. For losses induced by instabilities, interpretation is complicated by the fact that the loss foils observe only a small region of phase space, and that the losses often involve the synergistic effects of both core and edge instabilities.

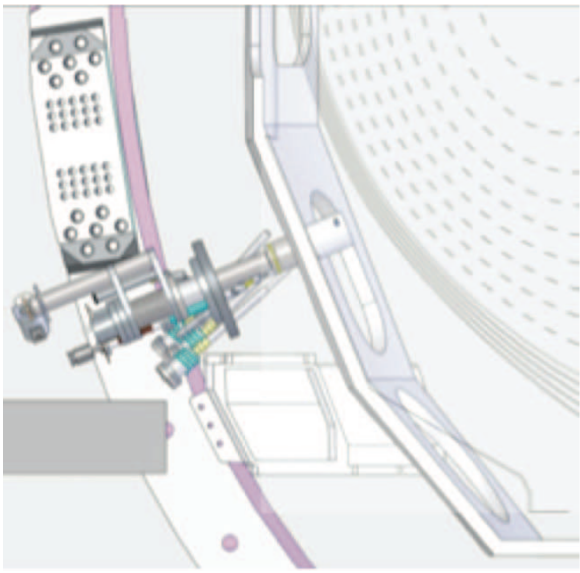

Fig. 3. Fast ion loss detector inserted past the first wall tiles and into the region outside the last closed plasma flux surface.

New Fast Ion Loss Detector

We are presently designing a new fast ion loss detector (FILD) to aid in studies of fast ions and instabilities in DIII-D. As shown in Fig. 3, this detector can be inserted past the first wall tiles and into the region outside the last closed plasma flux surface, which should allow the detection of escaping fast ions over a larger portion of phase space. The detector head measures fast ions that pass through a small collimator and strike a scintillator plate.

Measuring the two-dimensional light pattern on the scintillator yields information on both the perpendicular gyroradius and the pitch angle of the escaping fast ions, an approach first used to detect escaping DT alphas on TFTR [4], and more recently used to study fast ion losses on ASDEX Upgrade (AUG) [5]. Neither FIDA nor the existing energetic ion loss detectors on DIII-D presently have the fast time response needed to help determine how Alfvén eigenmode instabilities interact with the energetic ions. The TG-Green scintillator used on the AUG fast ion loss detector has a 490 ns decay time, high light generation (ionoluminescense) efficiency, and high saturation levels. The light pattern from the scintillator is imaged by a lens train, and a half-silvered mirror splits the light between a TV camera and an array of 20 fiber-coupled PMTs. The PMT array should allow measurements of the beam ion losses with the time response (>200 kHz) and detection sensitivity needed to study Alfvén eigenmodes. By correlating the beam ion loss results from the new FILD with the FIDA results and our observations of the internal mode structures, we hope to gain information on the fast ion loss orbits and the loss mechanisms involved in the instabilities.

The new DIII-D FILD, shown in plan view in Fig. 4, has a graphite heat shield covering the detector head with a single fixed oversize entrance aperture. The design includes a feature not found in the AUG design, a gear driven rotating concentric cylinder that allows the selection of any of five different entrance collimators. Based on the AUG design and results, the smallest aperture (~1 mm by 3 mm) should provide excellent pitch angle and gyroradius resolution, If this size collimator does not result in a fast ion loss signal with sufficient signal-to-noise ratio for Alfvén eigenmode studies, we will be able to choose a larger entrance aperture to provide larger signal levels at the expense of reduced gyroradius and/or pitch angle resolution.

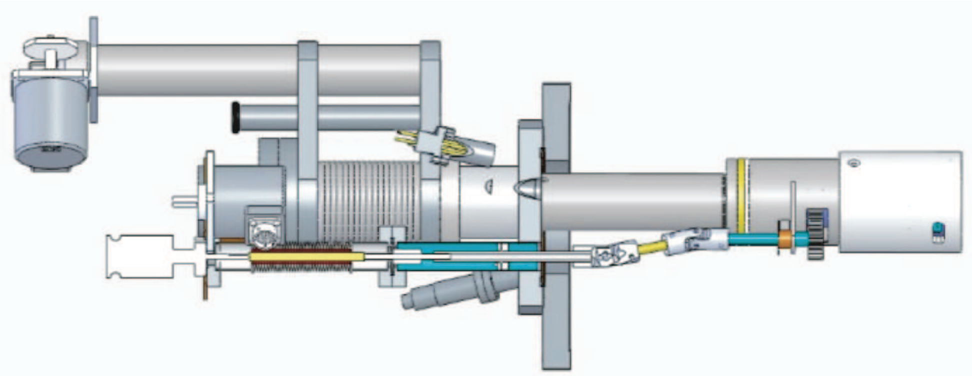

Fig. 4. CAD drawing showing new FILD with detector head on the right (plasma) side.

Future Plans

We propose to eventually install an array of fast ion loss detectors at several poloidal locations on the outer wall of DIII-D. One of the objectives of the new scintillator based DIII-D FILD is to measure the loss signal size, to aid in determining whether an array of fiber-coupled scintillator detectors or an array of Faraday collectors would be the best approach to observing losses due to AE activity.

The presence of a sufficiently large population of fast ions will destabilize AEs, which we know can then in turn cause the loss of these same fast ions. We have a good understanding of the basic properties of AEs themselves as evidenced by the agreement between theory and the measured mode structures inside the plasma. The next step is to better understand how Alfvén eigenmodes perturb the fast ion orbits and degrade their confinement. The interaction of the AEs with the fast ions is poorly understood. Using a poloidal array of fast ion loss detectors would allow measurements of the relative amplitude and phase of the loss signals at different poloidal locations to aid in the determination of the loss mechanism.

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