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Alfvén Instabilities During ICRF Minority Heating in TFTR*

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Instabilities in the Alfvén range of frequencies which are excited by energetic ions produced by ICRF heating[1,2] have the potential of interacting in turn with the energetic ion transport[3,4]. We initiated a large data base study of the ICRF experiments on TFTR to determine the characteristics of this interactive process and to discern the relative importance of two distinct groups of excited Alfvén modes -- Toroidal Alfvén Eigenmodes (TAE)[5] and Energetic Particle Modes (EPM)[4,6] -- with respect to energetic ion heating and confinement and consequently ICRF heating efficiency. We arrived at a picture in which core modes (EPM) play a fundamental role in the energetic ion transport.

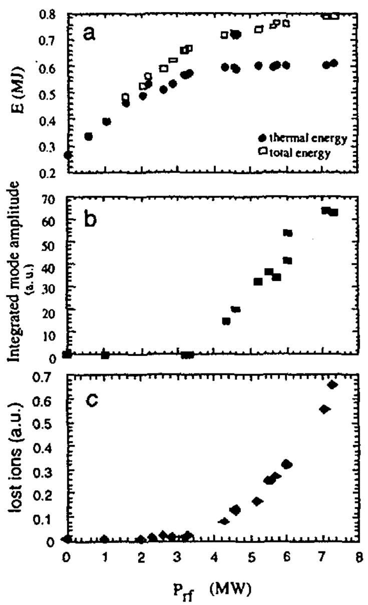

Fig. 1 Correlation between onset of MHD instabilities with fast ion losses and energy confinement degradation, versus rf power

Alfvén instabilities were observed in ICRF minority heating experiments in a variety of plasma conditions in TFTR. An array of Mirnov coils[7] was used to detect the MHD activity. The Mirnov data was compared in special situations with data from a reflectometer[8]. Ion losses were monitored with four probes placed at the edge of the plasma[9].

Figure 1a shows the increase of the total and thermal energy of the plasma as a function of rf power. Three stages are distinguishable. At first, the increase is linear and equal for the total energy and the thermal component. In this regime ion-ion collisions dominate and the minority ion distribution function does not present strong asymmetries[10]. Next, as the rf power and the minority ion energy increase, electron drag begins to dominate and an asymmetric part of the minority ion distribution function appears. During this phase low levels of fast ion loss are detected. Finally, at higher power (~4 MW) fast ion losses increase drastically and the Mirnov coils detect a signal which increases linearly with power. In this regime, confinement is clearly degraded.

The Alfvén spectrum can display two groups of modes, as shown in Fig. 2: one "stationary" in the sense that the frequency follows very closely the $(n_e)^{-1/2}$ dependence characteristic of Toroidal Alfvén Eigenmodes, and another group whose frequency "chirps". Both groups are usually made of several modes with well defined toroidal numbers. The TAE modes are global modes that are readily detected by the Mirnov coils. The chirping modes, which have a lower rf power threshold, have all the characteristics of Energetic Particle Modes (EPM). These modes can be detected by the Mirnov array almost exclusively in discharges with low q(a), but are otherwise detected by microwave reflectometry as density fluctuations deep in the plasma[11].

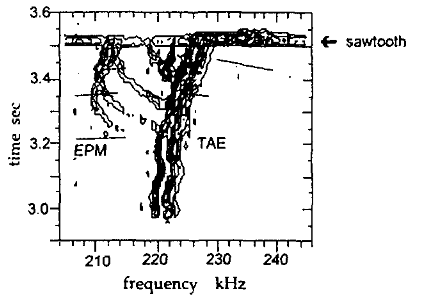

Fig. 2 Typical frequency spectrum from a Mirnov probe preceding a monster sawtooth crash.

Strong evidence from the data show that the energetic particle modes rather than the TAEs are responsible for most of the fast ion losses. The experimental data indicate that fast ions, generated mostly in the core by ICRF, excite EPMs. When their frequency decreases[6], the modes move outward carrying fast particles with them. While crossing the Alfvén gap the fast ions can modify or directly excite TAEs. A similar effect is observed when fast particles expelled from inside q=1 by a giant sawtooth flow across the Alfvén gap.

When the loss of fast particles from inside the q=1 surface becomes sufficiently large, a giant sawtooth takes place. Previous theory suggests that sawtooth stabilization by fast particles is lost when the beta of the energetic particles inside the q=1 surface drops below a critical level. These experiments provide a direct mechanism for the loss of the fast ion beta and subsequent collapse of the giant sawtooth. Furthermore, they point to a potential threat to the confinement of alpha particles under reactor conditions if EPM modes are generated.

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