Fast-ion energy loss during TAE avalanches in the National Spherical Torus Experiment

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The ability to predict the confinement and energy transfer rate of fast ions to the thermal plasma is important for optimizing the performance of ITER and other tokamaks. The presence of TAE or other MHD could impair the accurate modeling of beam driven currents that ITER and ST's rely upon. In this paper we report that modeling of the effect of TAE on fast ions finds that diffusion of fast ions in phase space, resulting in a net drop in fast ion energy, explains the observed neutron rate drop, without the need for significant fast ion loss or redistribution.

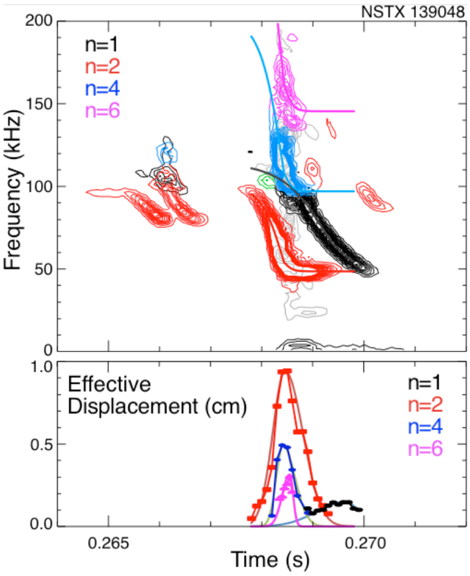

Fig. 1. a) Spectrogram of a Mirnov coil where contours are color-coded to indicate the toroidal mode numbers, as indicated in the legend, b) the peak mode amplitude evolution for each mode from the reflectometer array.

Fast ions on NSTX are known to be redistributed by low frequency MHD (kinks, NTMs), energetic particle modes and TAE avalanches, affecting the beam-driven current profile. Fast ion redistribution by avalanches has been successfully modeled in L-mode plasmas, using profile measurements of TAE amplitudes with a reflectometer array. Here we look at a relatively low-density H-mode plasma with enough core density peaking for mode amplitude measurements by several reflectometer channels.

The spectrogram of a Mirnov coil signal of the TAE avalanche at 0.268 s is shown in Fig. 1a. There are four important modes in this avalanche burst. The avalanche begins with the strong growth of an n=2 TAE which triggers n=4 and n=6 modes, and then an n=1 TAE. The peak amplitudes of these four modes, as measured with three internal reflectometer channels, are shown in Fig. 1b. In both Figs.

1a and 1b, the solid curves are analytic approximations to the frequency and amplitude evolutions which are used in the ORBIT code simulations described below.

The NOVA code, with the plasma equilibrium as input, is used to calculate linear eigenmodes for each of the four dominant modes in Fig. 2 to be used in ORBIT to simulate the affect on the fast ions. As NOVA is a linear code, we scale the eigenmodes so that the simulated reflectometer response matches the amplitude of the reflectometer signals. The experimental modes are clearly non-linear, with strong frequency chirping, so the experimental frequency evolutions are also used in ORBIT. Since, within experimental uncertainty, the mode structure is not strongly changed during the burst, use of linear modes is justified.

Simulations with ORBIT find very small fast ion losses at the nominal measured mode amplitudes. The threshold for fast ion losses is about twice the measured mode amplitude. However, the ≈ 10 % drop in neutron rate is roughly consistent with the ≈ 4% drop in energy in the fast ion population caused by the modes. The strong energy dependence of the fusion cross-section amplifies the ≈ 4% net energy drop, resulting in an ≈ 10 % neutron rate change. As the neutron production in NSTX is primarily beam-target, the change in beam-target reaction rate can be estimated as the change in $\Sigma\sigma(E_n)v_n$, where the sum is over the fast ion population (redistribution is ignored here as the density profile is relatively flat). The total neutron rate change, from energy drop and fast ion loss, is shown as the red points in Fig. 2 for various assumed mode amplitudes in ORBIT. The blue points show change in neutron rate from only fast ion losses. The fast-ion losses show a stochastic-like onset with mode amplitude, in contrast to energy loss which is nearly linear with mode amplitude. While ORBIT and NOVA do not self-consistently model the mode growth and fast ion transport, it might be assumed that the energy lost from the fast-ion distribution would transfer to the TAE. An estimate of the wave energy in the TAE burst is comparable to the decrement of energy in the fast-ion population at the observed mode amplitude.

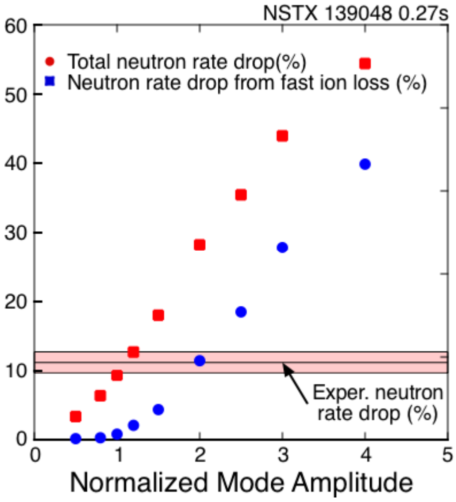

Fig. 2. Simulated beam-target neutron rate drop due to fast ion losses (blue) and stochastic cooling of fast ion distribution and losses (red).

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