Parametric dependence of fast-ion transport events on the National Spherical Torus Experiment

E. D. Fredrickson, N. N. Gorelenkov, M. Podesta, A. Bortolon[1], S. P. Gerhardt, R. E. Bell, A. Diallo, B. LeBlanc
PPPL, Princeton NJ
[1]*Univ. of Tennessee, Knoxville, Tennessee*
Email contact of main author: efredrickson@pppl.gov

Neutral-beam heated tokamak plasmas commonly have more than one third of the plasma kinetic energy in the non-thermal energetic beam ion population. This population of fast ions heats the plasma, provides some of the current drive, and can affect the stability (positively or negatively) of magneto-hydrodynamic instabilities. This population of energetic ions is not in thermodynamic equilibrium, thus there is free-energy available to drive instabilities, which, of course, leads to redistribution of the fast ion population. Understanding the conditions under which beam-driven instabilities arise, and the extent of the resulting perturbation to the fast ion population, is important for predicting and eventually demonstrating non-inductive current ramp-up and sustainment in NSTX-U, as well as the performance of future fusion plasma experiments such as ITER, where both the fusion α's and the beam ions will have $V_{fast}/V_{Alfvén}>1$. This paper presents an empirical approach towards characterizing the stability boundaries for some common energetic-ion-driven instabilities seen on NSTX.

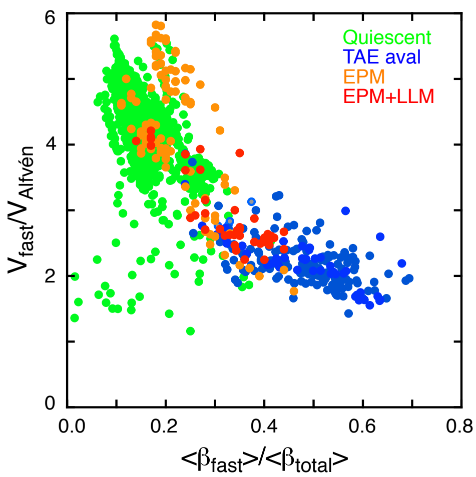

Fig. 1. Existence plot for TAE avalanches (blue), fishbone-like EPM (orange), EPMs coupled to long-lasting-modes (LLM), as well as quiescent plasmas with weak or no MHD activity (green).

A database was constructed by dividing each of ≈360 NSTX TRANSP runs into 50ms intervals, starting at 150ms. The MHD activity in each 50ms interval was subjectively classified as, *e.g.*, having TAE avalanches, energetic particle modes (EPMs), or plasmas quiescent in the TAE and lower frequency range. Typically by 150ms NSTX plasmas have reached a plasma current of 0.6MA to 0.7MA, and fast ion confinement is reasonably good. The 50ms time interval is several fast-ion slowing down times, and it is comparable to the timescale for evolution of MHD phenomena.

Figure 1 is constructed from this database and the color of each point indicates the type of instability dominant in that interval. The horizontal axis is the ratio of the fast ion beta, β_{fast}, to the total plasma beta, β_{total}. The vertical axis is the ratio of the birth velocity of the full-energy beam ions normalized to an average Alfvén speed. Generally, NSTX shots evolve, starting from the lower right of Fig. 1 and move upwards and to the left as the plasma density increases. The quiescent discharge periods (green), and periods with TAE avalanches (blue in Fig. 1) are well localized in this parameter space. Quiescent plasmas mostly have a ratio of fast-ion stored energy to total stored energy of less than ≈ 30%. Conversely, the TAE avalanches events occur where that ratio, $\beta_{fast}/\beta_{total} > 0.3$. Within this dataset, there does not seem to be a significant dependence on the parameter $V_{fast}/V_{Alfvén}$.

The empirical scaling of neutron rate drops versus the peak mode amplitude as measured by a Mirnov coil, is shown in Fig. 2 for TAE avalanches (green) and EPMs (red and blue). The neutron rate drops follow an offset-linear scaling with mode amplitude, suggesting an amplitude threshold for the onset of the avalanche. The peak EPM edge magnetic fluctuation level tends to be larger that that for TAE avalanches for a similar drop in the normalized neutron rate. The scaling of the neutron rate drop with edge magnetic fluctuation amplitude is similar for the two types of fishbone-like EPMs, although there is considerably more scatter for the EPM coupled to the long-lived mode. Some of the scatter could reflect the variations in scaling of edge magnetic fluctuations to core mode amplitudes.

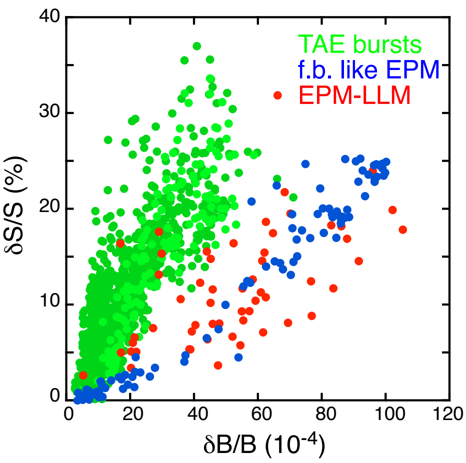

Fig. 2. Scaling of neutron rate drops with edge magnetic fluctuation amplitude for TAE (green), fishbone-like EPM (blue) and EPM coupled to long-lived modes (red).

On NSTX the TAE avalanches and fishbone-like Energetic Particle Modes are predominantly responsible for fast ion redistribution events. The dependence of these events on plasma global parameters has been studied. It has been shown that for this NSTX data set, TAE avalanching is only seen when the calculated $\beta_{fast}/\beta_{total} > 0.3$, and conversely, that quiescent plasmas are only seen for $\beta_{fast}/\beta_{total} < 0.3$.

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