§ 3. Simulation of Intermittent Beam Ion Loss in a Tokamak Fusion Test Reactor Experiment

Todo, Y.
Berk, H.L., Breizman, B.N. (IFS, Univ. Texas at Austin)

The toroidicity-induced Alfvén eigenmode (TAE) can be destabilized by fast ions that have velocities comparable to the Alfvén velocity. A decade ago recurrent bursts of TAEs were observed with drops in neutron emission during neutral beam injection (NBI) in the Tokamak Fusion Test Reactor (TFTR) [1] and DIII-D [2]. The drops in neutron emission have been recognized as a manifestation of TAE-induced beam ion loss. In the experiments cited multiple TAEs were destabilized during TAE bursts that took place at regular time intervals. The modulation depth of the drop in neutron emission in the TFTR plasma was typically ~10%. The most important result is that the beam confinement time is about one-half to one-third of the collisional slowing-down time. This means that TAE activity expels beam ions before their energy is absorbed by the core plasma.

We have carried out simulations [3] based on a reduced MHD method, for a configuration typical of the TFTR experiment with balanced beam injection. The simulation uses a perturbative approach where the TAE spatial profile is assumed fixed, while amplitudes and phases of the eigenmodes and the fast-ion nonlinear dynamics is followed self-consistently. For simplicity we consider concentric circular magnetic surfaces to describe the equilibrium magnetic field. For the TAE burst simulation the q-profile is taken to vary quadratically with minor radius from a central value of 1.2 to an edge value of 3.0. The major and minor radii are R_0 =2.4 m and a=0.75 m. The magnetic field is 1.0 T on axis. Five eigenmodes are taken into account. The linear damping rate of each mode is assumed to be constant at $4\times10^3\mathrm{s}^{-1}$. Beam ions have balanced injection with a constant heating power of 10 MW and with a spatial Gaussian profile whose radial scale length is 0.3m. The injection energy is 110 keV which corresponds roughly to the Alfvén velocity parallel to the magnetic field. In the TFTR experiment two types of limiters, toroidal belt limiter and three poloidal limiters, were used. In the poloidal cross section the limiters roughly defined a circle of radius 1m. We model these limiters by removing particles if they reach a torus of minor radius 1m. Thus the plasma is leaning on the limiter on the strong field side, while on the weak field side at the midplane there is a 0.5m space between the plasma edge and the limiter. The slowing-down time is assumed to be 100 ms. The number of particles used is 2.1×10^6.

We start the simulation at an initial time taken as t=0 when the beam ions are first injected. As time passes, energetic ions gradually accumulate. Synchronized bursts take place recurrently at a burst interval that is roughly 2.9 ms which closely matches that of experimental value 2.2 ms in the TFTR experiment that we are comparing with. The volume average beam ion beta value saturates at 0.6%, which corresponds to 0.4 of the classical distribution. We find a good agreement in simulation and experiment. Figure 1 shows the time evolution of the dominant two modes 2 and 5 and the density of the co-injected beam ions. We can see that the mode 2, which is located at the plasma center, has precursory growth before both the modes grow together during each burst. Because the beam injection profile peaks at the plasma center, mode 2 is destabilized before mode 5. We can see a complete flattening of the density at the plasma core (r/a<0.72) while small increase in the density at the plasma edge (r/a>0.72). The beam ions stored at the plasma core during the quiescent phases are transported to the plasma edge and lost during the bursts.

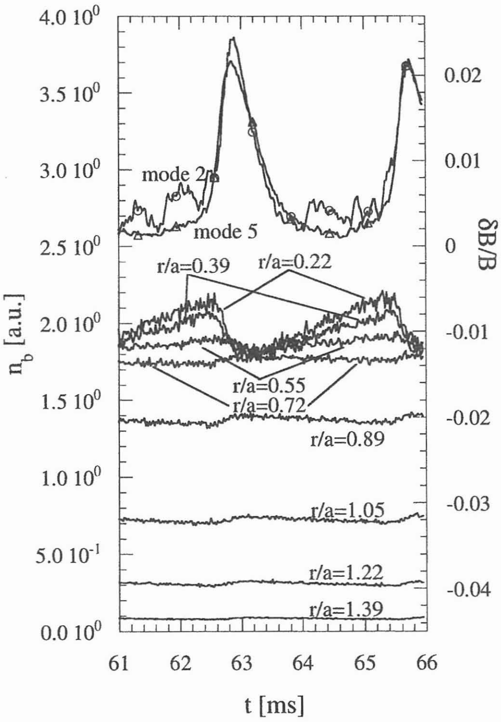

Fig.1. The time evolution of the dominant two modes 2 and 5 and the density of the co-injected beam ions at various minor radius.

[1] K. L. Wong *et al.*, Phys. Rev. Lett. **66**, 1874 (1991).
[2] W. W. Heidbrink *et al.*, Nucl. Fusion **31**, 1635 (1991).
[3] Y. Todo *et al.*, Phys. Plasmas **10**, 2888 (2003).