§21. Energetic Ion Transport due to Alfvén Eigenmode Bursts

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The toroidicity-induced Alfvén eigenmode (TAE) can be destabilized by fast ions which have velocities comparable to the Alfvén velocity. A decade ago recurrent bursts of TAEs were observed with neutral beam injection (NBI) in the Tokamak Fusion Test Reactor (TFTR) [1] and DIII-D [2] experiments. Nearly synchronous with these TAE excitations, there were observed drops in neutron emission. Hence it was inferred that the TAE excitations caused a direct loss of the injected beam ions. In the experiments cited multiple TAE mode bursting at regular time intervals were observed. The modulation depth of the drop in neutron emission in the TFTR plasma was typically ~10% (Fig. 4 of Ref. [1]) and the beam confinement time is about one-half to one-third of the collisional slowing-down time. This means that the TAE activity in these experiments substantially reduced the beam ion energy confinement time because TAE activity expels a substantial fraction of the energetic beam ions before this energy is absorbed by the core plasma through drag that is caused by classical collisions.

Recently, simulations, based on a reduced magnetohydrodynamic (MHD) method for a configuration typical of the TFTR experiment which had balanced beam injection [1], were carried out and the results were reported in Ref. [3]. The results of the simulation reproduced quite closely the following aspects of the experimental parameters; a) synchronized bursts of multiple TAEs taking place at regular time intervals close to the experimental value; b) a modulation depth in the stored beam energy that is close to the one inferred in experiment; c) stored beam energy that is about one-third of the classical slowing-down distribution. Only co-injected beam ions build up to a significant stored energy even though their distribution is flattened in the plasma center. They are not directly lost as their orbits extend beyond the outer plasma edge when the core plasma leans on a high field side limiter.

The effects of the distance from the plasma edge to the limiter are important for energetic ion confinement. Configuration of the plasma and the limiter, and examples of counter-injected beam ion orbit and co-injected beam ion orbit are shown in Fig. 1. To demonstrate it, we carried a run where the distance to the limiter in the low field side is decreased after the stored beam energy reaches roughly a constant level [4]. The distance from the plasma edge to the limiter in the low field side Δ is decreased in 30ms after t=66.8ms. We can see in Fig. 2 that the stored energy of co-injected beam drops rapidly after Δ/a is reduced to about 0.3. The KAM surfaces exist at $4.4<R/a<4.6$ for co-injected beam ions, which do not allow the particle diffusion from the plasma center to the edge and lead to substantial delay in particle loss compared with the counter-injected beam ions. After Δ/a becomes less than about 0.3, the limiter comes inside the KAM surfaces leading to disappearance of this effective barrier. After Δ/a reaches 0, the time evolution of the stored energy of the co-injected beam is roughly the same as that of the counter-injected beam. Thus, it is clear that the difference in the stored energy of the co and counter beams before t=66.8 ms was created due to the limiter configuration which allows only the co-injected beam ions to stick out of the plasma. We see in Fig. 2 that as Δ decreases in time after t=66.8 ms, the burst interval becomes longer. After Δ reaches 0 at t=96.8ms, the burst intervals are about 5ms.

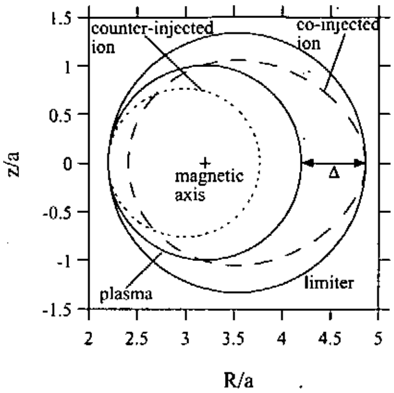

Fig. 1 Configuration of the plasma and the limiter, and examples of counter-injected beam ion orbit and co-injected beam ion orbit. The velocity of the co-injected ion is parallel to the plasma current. The orbits of co-injected (counter-injected) beam ions are displaced from magnetic surfaces towards the low (high) field side. The distance from the plasma edge to the limiter in the low field side is denoted as Δ.

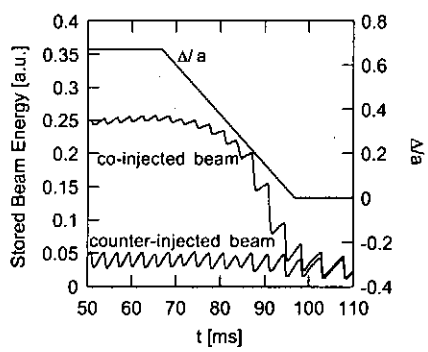

Fig.2 Time evolution of the distance from the plasma edge to the limiter in the low field side (denoted as Δ) and of the stored energy of co and counter injected beams.

References

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[3] Y. Todo, H. L. Berk, and B. N. Breizman, Phys. Plasmas **10**, 2888 (2003).
[4] Y. Todo, H. L. Berk, and B. N. Breizman, "Energetic Ion Transport due to Alfvén Eigenmode Bursts", to appear in Proc. 13th International Toki Conference on Plasma Physics and Controlled Nuclear Fusion.