4-11 Fast Ion Transport Study Using HELIOS

— Fast Ion's Dance with Alfvén Waves in ITER Plasma —

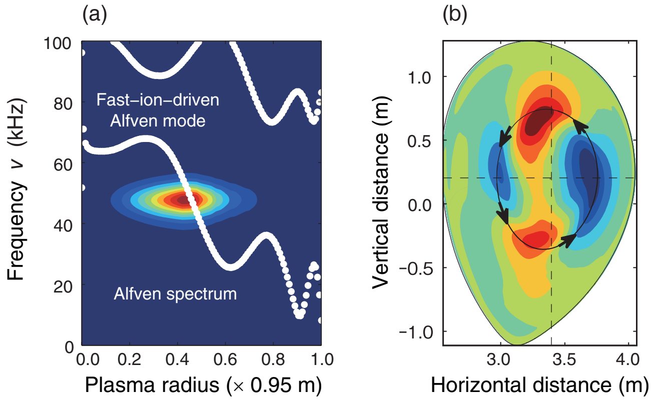

Fig.4-26 Properties of the fast-ion-driven Alfvén mode

(a) Radial profile and frequency. The radius is normalized by the volume-averaged plasma radius of 0.95 m. The mode frequency of 45 kHz is consistent with experimental data, in which mode activity in the 30 – 70 kHz range is observed, and lies precisely on the continuous Alfvén spectrum (white dots).

(b) Mode structure in the poloidal cross section of the torus. The mode has toroidal mode number 1, consistent with experimental results.

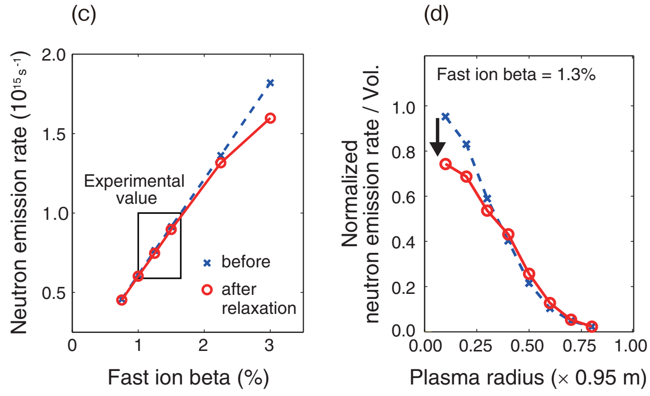

Fig.4-27 Effect on the neutron emission rate

(c) Dependence of the neutron emission rate on the fast ion beta. The box indicates experimental values, which are reproduced with beta values around 1% – 1.5%.

(d) Radial profile of the neutron emission rate per unit volume, normalized by the central value of the initial profile Blue: initial, red: after relaxation. As in the experiment, the central value decreases by 25% when the initial fast ion beta used in the simulation is 1.3%. This is half the beta predicted by classical calculations without Alfvén waves.

ITER is an experimental reactor intended to create the conditions required to sustain nuclear fusion reactions that can serve as a source of energy. It will confine deuterium-tritium plasmas at 100 million degrees Celsius and produce neutrons and helium ions via fusion reactions. The helium ions are born with a kinetic energy 100 times larger than that of the bulk plasma and are used to heat it via collisions. However, the fast helium ions move with a rhythm that is similar to that of plasma waves called Alfvén waves, so they dance together and exchange energy. If the waves reach large amplitudes, the fast ions are pumped out of the confinement region. Thus, it is important to evaluate the fast ion transport.

Together with the National Institute for Fusion Science, we conducted simulations of fast ion transport using HELIOS, a supercomputer operated by the International Fusion Energy Research Center. The simulation model was validated by simulating scenarios from the JT-60U fusion experimental device and by comparing the results with experimental data. To mimic the ITER conditions in JT-60U, energetic deuterium ions were introduced by powerful beams. The fast ions were observed to drive intensive cyclic bursts of Alfvén wave activity. Because the bursting phenomena depend on the form of the fast ion distribution in phase space, a novel method was developed that allows us to initialize simulations with fast ion distributions computed by an orbit-following Monte Carlo code for realistic beam geometry and collisions.

The simulation results show that the frequency and mode number of the instability, which triggers profile relaxation accompanied by the burst, are consistent with experimental observation (Fig.4-26). By varying the fast ion beta value, we obtained a value that reproduced the fast ion redistribution and the resulting changes in the neutron emission rate seen in experiments (Fig.4-27). In classical calculations, the total neutron emission rate is overestimated because Alfvén wave activity is not taken into account. Our simulations indicate that the true value of the confined fast ion beta is about a factor of two lower.

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Reference

Bierwage, A. et al., Role of Convective Amplification of n =1 Energetic Particle Modes for N–NB Ion Dynamics in JT–60U, Nuclear Fusion, vol.53, no.7, 2013, p.073007–1–073007–12.