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Comprehensive magnetohydrodynamic hybrid simulations of fast ion losses due to the Alfvén eigenmodes in the Large Helical Device

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In the large helical device (LHD), the fast ion confinement has been investigated by using three tangentially injected neutral beams (NBs) with 180 keV fast ions and/or two perpendicularly injected NBs with 40-80 keV fast ions. The Alfvén eigenmodes (AEs) are observed during the tangential-NB injections [1,2]. These fast ion driven instabilities enhance the fast ion losses. It is important to identify the instabilities and clarify the properties of the lost fast ions due to the instabilities.

A hybrid simulation code for nonlinear magnetohydro-dynamics (MHD) and energetic-particle dynamics, MEGA, has been developed to simulate recurrent bursts of fast ion driven instabilities including the energetic-particle source, collisions and losses [3]. In order to simulate the formation process of the fast ion distribution including the fast ion redistribution brought about by the AEs, the multi-phase MHD hybrid simulation, which is a combination of classical simulation and MHD hybrid simulation, has been developed.

In order to identify the instabilities and to clarify the process of the fast ion losses in the LHD experiments, the multi-phase simulation with MEGA is applied to the LHD plasmas, where fast ion driven instabilities and lost fast ion properties are investigated by using tangential-NBs [1], with the realistic conditions close to the experiments. The time evolution of the instabilities and the stored fast ion energy are shown in Fig. 1 (a) and the fast ion loss rate is shown in Fig. 1 (b). The fast ions that reach the divertor region are identified as lost particles, and the fast ion loss rate is measured every 0.01 ms. In Fig. 1 (a), the AE bursts occur recurrently, and the stored fast ion energy is smaller than that of the classical calculation [Fig. 1 (a)]. As a result, the stored energies are saturated at an earlier time than the classical calculation. The fast ions are significantly lost during the AE bursts. At the saturation state of stored fast ion energy, the fast ion loss rate during the classical phase of the multi-phase simulation is also larger than that of the classical calculation as shown in Fig. 1 (b). This enhancement of fast ion loss during the quiescent phase of AE burst can be attributed to the redistribution of fast ions during the AE bursts towards the plasma edge.

Figure 2 shows the AE-induced fast ion loss rate versus the maximum AE amplitude for each burst. The primary harmonic of radial MHD velocity for the AE is m/n=2/1. We see that the fast ion loss rate brought about by the AE burst is proportional to the square of AE amplitude. This quadratic dependence of fast ion loss indicates the emergence of stochasticity in the fast ion loss process and was measured in the LHD experiments[2].

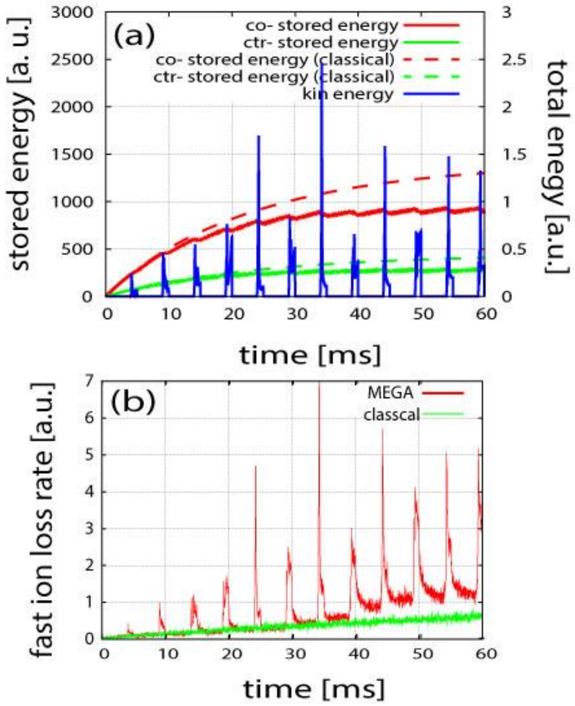

Fig. 1 Time evolution of stored fast ion energy and fast ion loss rate. In these figures, the results of classical slowing down calculation are also shown.

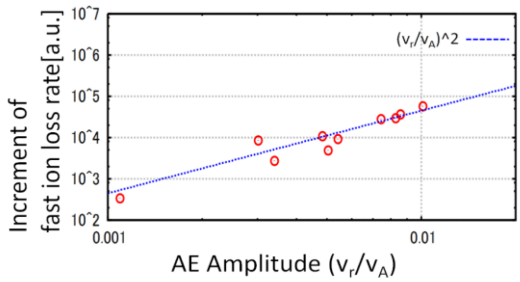

Fig. 2 AE-induced fast ion loss rate versus maximum AE amplitude (radial MHD velocity normalized by Alfvén velocity) for each burst.

Reference
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