§59. Studies of Magnetic Configuration Effects on TAE-induced Fast Ion Losses in LHD by an Orbit Following Model

Ogawa, K., Isobe, M., Toi, K., Spong, D.A. (ORNL), Osakabe, M., Yamamoto, S. (Kyoto Univ.), LHD Experiment Group

A study of toroidal-Alfvén eigenmode (TAE) induced fast-ion losses has been carried out over wide parameter ranges of the Large Helical Device (LHD) plasmas. The dependence of the observed TAE-induced fast-ion loss with respect to TAE fluctuation amplitude indicates that the magnetic axis shift increases the fast-ion loss due to TAE and transitions the loss process. TAE-induced loss simulation based on two-orbit following codes considering the time-varying TAE fluctuation amplitude with the electric polarization potential due to rapid electron response was carried out. It indicates that the magnetic axis shift leads to not only increase of lost fast ion flux due to TAE but also the expansion of the energy and pitch angle region of escaping fast ions.

Much attention has been given to the interaction of TAE instabilities with fast ions in toroidal plasmas in order to avoid local damage on the plasma-facing component as well as a degradation of the plasma performance. In LHD, these studies are performed at relatively low toroidal field Bt so that beam ions are super Alfvénic. A great deal of effort has been directed toward observation of fast-ion transport and/or loss induced by TAE using a neutral particle analyzer and a scintillator-based lost-fast ion probe (SLIP) in the configuration of R_{ax}=3.6 m on plasmas with large Shafranov shift [1, 2]. In this work, effort has been made to reveal the magnetic configuration effects on TAE-induced fast-ion losses with the aid of detailed fast-ion loss modeling which incorporates TAE fluctuations.[)]

Measurements of fast-ion losses induced by TAE instabilities are conducted with neutral beam (NB)-heated LHD plasmas having various magnetic axis positions R_{mag}. These TAEs have m/n=1+2/1 structure and a peak at r/a~0.6 [1]. Here, m, n and r/a represent poloidal mode number, toroidal mode number and normalized minor radius, respectively. The SLIP and Mirnov coil installed outside the plasma were employed to measure fast-ion losses and TAE fluctuation amplitude b_{TAE}, respectively. A plot of fast-ion loss induced by TAE $\Delta\Gamma_{SLIP}$ as a function of b_{TAE} is shown in Fig. 1. Here, $\Delta\Gamma_{SLIP}$ is normalized by fast-ion populations created by co-injected NB ($P_{NBco}\tau_{se}$). As can be seen, fast-ion losses monotonically grow with b_{TAE} in all the cases. Note that fast-ion losses increase substantially as R_{mag} is increased due to finite plasma pressure. It indicates not only loss flux increases but also convective type losses ($\Delta\Gamma_{SLIP} \propto b_{TAE}$) transitions to diffusive ($\Delta\Gamma_{SLIP} \propto b_{TAE}^2$) or stochastic losses ($\Delta\Gamma_{SLIP} \propto b_{TAE}^a$: a>2) arising from increased R_{mag} shift [3]. Thus, magnetic axis shift affects the loss process of TAE-induced loss.

Simulations based on orbit following models that include the TAE fluctuations are performed to study the loss mechanism in plasmas with R_{ax} of 3.60 m. TAE fluctuation is modeled as $\boldsymbol{b}=\nabla\times(\alpha\boldsymbol{B})$, where α represents a general function of the position, amplitude and frequency of the magnetic fluctuation. Electric polarization potential due to rapid electron response is included because ion motion is modified by the mobility of the electrons that makes the electric field parallel to the magnetic field equal to zero. The simulation is composed of two-orbit following codes: (a) the DELTA5D code [4] applicable only to plasma region including the TAE and (b) the Lorentz orbit code applied to the vacuum region outside the plasma. Orbits followed by both codes are connected consistently at the last closed flux surface. The dependence of the fast-ion losses on the TAE fluctuation amplitude at the mode center b_{TAE0} is shown in Fig. 2. Note that b_{TAE0} is expected to be nearly proportional to b_{TAE} in each configuration, because the observed TAEs are located in the outer region. Numerical simulation has successfully reproduced the experimental result; Shafranov shift causes increased transport of fast ion and stronger loss dependence on fluctuation amplitude. The simulation indicates that the increased power of the dependence shows the expansion of the energy and pitch angle region of fast ions lost from the plasma due to TAE.

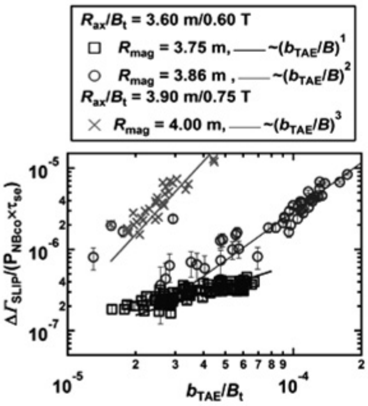

Fig. 1 Increment of fast-ion losses measured by the SLIP due to TAE $\Delta\Gamma_{SLIP}$ dependence on TAE amplitude at the Mirnov coil b_{TAE}/B_t.

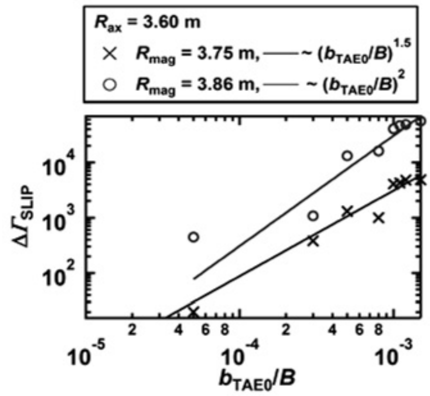

Fig. 2 Fast-ion loss due to TAE $\Delta\Gamma_{SLIP}$ dependence on fluctuation amplitude at TAE peak b_{TAE0}/B in calculation.

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