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Observation of TAE Induced Convective/Diffusive Losses and Comparison with Orbit Following Model in LHD
大型ヘリカル装置におけるトロイダルアルヴェン固有モードに起因する対流・拡散損失の観測と、粒子軌道シミュレーションとの比較

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Fast ions lost from the LHD plasma due to toroidal Alfvén eigenmode (TAE) together with the energy E and the pitch angle χ of them is measured by the scintillator-based lost-fast ion probe (SLIP). The number of lost fast ions detected by the SLIP grows with the increase of the magnetic fluctuation amplitude, and the dependence becomes steeper as the increase of Shafranov shift. Fast ion loss due to TAE is simulated with orbit following models. The loss-flux dependence on magnetic fluctuation has the same tendency as obtained in experiments.

1. Introduction

One of the critical issues in realizing self-sustained DT burning plasma is that how well fast ions such as alpha particles will be confined. Better understanding on the loss process of fast ions due to fast-ion-driven MHD instabilities is required to find a scenario to control and/or reduce fast-ion loss [1]. In the large helical device (LHD), the anomalous transport or loss of co-going beam ions due to toroidal Alfven eigenmodes (TAEs) [2] have been recognized by an E//B neutral particle analyser with a tangential line of sight [3] and a scintillator-based lost fast ion probe (SLIP) [4] in the position of magnetic axis in vacuum R_{ax} of 3.60 m with a large Shafranov shift plasma. Understanding on the anomalous transport and the consequent fast ion loss due to TAEs, a magnetic configuration effect on the fast ion loss needs to be studied. At the same time, a modelling of the fast ion loss caused by TAEs is also the task.

2. TAE induced loss measured on a plasma with small and large Shafranov shift

Experiments of TAE excitation were conducted in LHD. Strong TAE modes are excited using three neutral beam injectors (NBIs); its acceleration-energy is up to 190 keV. The SLIP gives the energy E and the pitch angle χ of the lost fast ion simultaneously [5]. Mirnov coil array set on the vacuum vessel measures the amplitude of the fluctuation of TAE modes b_{TAE} and the toroidal/poloidal mode number (m and n).

The study on TAE induced loss was conducted at relatively-low-field experiments (B_t=0.60 T) on R_{ax} of 3.60 m with a small Shafranov shift (R_{mag} of 3.75 m) and a large shift (R_{mag} of 3.86 m). TAE having m/n=1/1 induced loss is observed in the range of E/χ ~50~190 keV/~40°. The normalized energetic ion loss flux due to TAE $\Delta\Gamma_{SLIP}/P_{NBco}\tau_{se}$ dependence on b_{TAE}/B_t is shown in Fig. 1. Here, the $\Delta\mathit{\Gamma}_{SLIP}$ is normalized by the energetic ion content generated by co-injected NBIs (P_{NBco} τ_{se}). Loss flux dependence on magnetic fluctuation amplitude indicates convective type at the plasma with small Shafranov shift and indicates diffusive type loss at the plasma with large Shafranov shift, respectively [6]. The Shafranov shift can modify the safety factor profile appreciably and also expand the loss boundary because of large orbit deviation from the magnetic surfaces [7, 8]. TAE induce the resonant drift near the loss boundary at small-shift case. On the other hand, fast ions transported diffusively due to the relatively large amplitude and wider TAE to loss domains on a large shift case.

3. TAE induced loss reaching the SLIP in the calculation

Simulation of fast ion losses due to TAE is demonstrated based on the orbit following model with a TAE fluctuation. Equilibrium is reconstructed using VME2000 [9] with using the electron temperature T_e and the electron density n_e

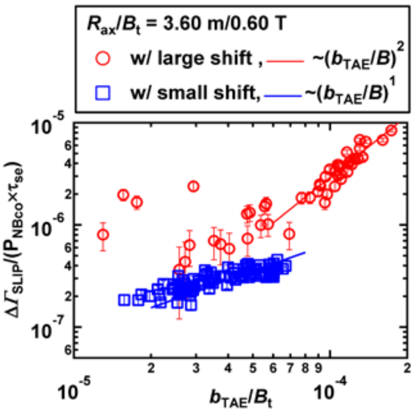

Fig.1. Fast ion loss flux dependence on fluctuation amplitude of TAE measured with magnetic probe.

profile measured with the Thomson scattering diagnostics [10]. A birth profile and the initial pitch angle of beam ions are given by HFREYA [11] using the profile of T_e and n_e and the position of ion sources. Guiding-centre orbit of each beam ion in the boozer coordinate is followed using DELTA5D [12] including the TAE fluctuations. The fluctuation is assumed as $\mathbf{b} = \nabla\times(\alpha\mathbf{B}) : \alpha = \nabla_{//}\phi$, where b and ϕ indicate the magnetic fluctuation and the eigenfunction of the mode, respectively [13]. ϕ is obtained using AE3D [14] code by assuming the charge neutrality n_i = n_e, and the pure hydrogen plasma (Z_{eff}=1). An orbit from the last closed flux surface to the SLIP is followed using the Larmor orbit code with using the magnetic field in a vacuum. We judged a fast ion reaches the SLIP if distance between a guiding-centre orbit and a Lorentz orbit is in the poloidal Larmor radii ±20 %, the difference of pitch angle is less than 5 degrees, and the energy difference is less than 5 keV. In these calculations, the TAE fluctuation is included after a slowing down of the fast ions and sums all the results to simulate the slowing-down profile of fast ions. Frequency of the mode in the calculation is down from 70 kHz to 50 kHz in 1 ms. An increment of loss induced by TAE dependence on fluctuation amplitude at the TAE peak b_0 is shown in Fig. 2. The loss flux grows with the increase of b_0 and Shafranov shift. The loss flux dependence on b_0 becomes steeper as increase of Shafranov shift. These tendencies agree with that of the experiments.

4. Summary

Measurement of E and χ of lost fast ions induced by m/n=1/1 TAE were carried out on R_{ax} = 3.60 m with a small and a large Shafranov shift. The normalized loss flux grows with the increase

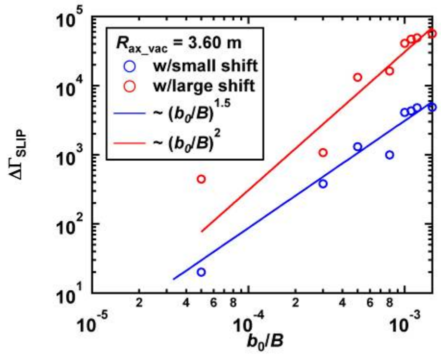

Fig.2. Fast ion loss flux dependence on fluctuation amplitude at the TAE centre in calculation.

of the TAE amplitude measured with the Mirnov coil set on vacuum vessel. TAE induced loss becomes larger and the loss flux dependence on b_{TAE} becomes steeper at large shift case than small shift case. Wider eigenfunction of TAE and an expansion of loss region are candidate to explain the changing. TAE induced loss is simulated using the orbit following model using DELTA5D and Lorentz orbit code. The loss flux induced by TAE grows with increasing of b_0 and R_{mag} shift as obtained in the experiments.

Acknowledgments

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