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ヘリカル系における高エネルギーイオンの動力学と理想電磁流体力学的不安定性
Fast-ion dynamics and ideal magnetohydrodynamics instability in helical systems

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In torus plasmas, such as tokamaks and helical systems, fast ions are produced by neutral beam injection and/or nuclear fusion, which have much higher energies than those of thermal ions. To understand interaction between fast ions and magnetohydrodynamics (MHD) instability is one of important issues for plasma confinement, because fast-ion-driven MHD instability gives rise to anomalous losses of fast ions and degradation of efficiency of plasma heating.

Recently, MHD activities with low frequencies compared with the Alfvén wave transit frequency are observed during the perpendicular neutral beam injection in the Large Helical Device[1], and theoretical models are required to understand such phenomena. In comparison with tokamaks, the fast-ion-driven MHD instability has not been fully investigated in helical systems, except high-frequency Alfvén eigenmodes destabilized by passing fast ions, because complicated magnetic fields in helical systems make it difficult to calculate MHD stability, fast-ion orbit, and fast-ion distribution.

In this presentation, we firstly discuss fast-ion motion in the presence of magnetic field ripple in helical systems. An equation of motion for a guiding center of single fast ion is introduced, and particle trapping mechanism and precession drifts of trapped particles, where guiding centers of trapped particles helically circulate in magnetic fields, are reviewed. The bounce frequency and the poloidal (or toroidal) rotation frequency by the precession drift are evaluated in typical parameters of the LHD.

Next, we discuss a theoretical framework of the stability analysis of the fast-ion-driven MHD instability in helical systems. If the ideal MHD instability is considered, the simplest method is the energy principle

$$\delta I + \delta W_{MHD} + \delta W_K = 0, \tag{1}$$

where δI is the change of the kinetic energy of the MHD fluids, δW_{MHD} is the change of the field energy of the MHD fluids, and δW_K is the change of the kinetic energy of the fast ions. An evaluation of δW_{MHD} is complicated in helical systems, but it is drastically simplified by introducing linearized reduced MHD equations[2]. The classical linear gyrokinetic equation is necessary to evaluate δW_K[3], taking into account helically winding magnetic fields. We expect that the final form of Eq. (1) might correspond to a dispersion relation of the fast-ion-driven MHD instability, where the complex eigenfrequency and the characteristic frequency of fast ions are involved. Progress on this approach is reported in the presentation.

[1] X. D. Du, et al., *'First Observation of Fishbone-like Modes Driven by Helical-Ripple Trapped Fast Ions on LHD'*, 13th IAEA Technical Meeting on Energetic Particle Physics in Magnetic Confinement System.
[2] H. R. Strauss, Phys. Plasmas **22** (1980) 733.
[3] Liu Chen, R. B. White, and M. N. Rosenbluth, Phys. Rev. Lett. **52** (1984) 1122.