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Simulation Study of Energetic Particle-driven MHD Modes and Energetic Particle Redistribution in Heliotron J

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Sufficiently long energetic particle (EP) confinement time is important for realizing self-sustainable plasma; however, these EPs can resonate with the shear Alfvén waves (SAW) through fundamental and sideband resonances in the magnetic confinement fusion devices (e.g. tokamak and stellarator/heliotron). In this study, we analyzed the stability of the EP-driven MHD instabilities and their effects on the EPs confinement in Heliotron J, a low shear helical axis stellarator/heliotron device. The three-dimensional magnetic field of Heliotron J is mainly composed of the helicity, toroidicity, and bumpy Fourier components. This creates additional interactions between EP and SAW[1-2]. The stabilities and EPs confinement are analyzed by MEGA[4], a hybrid MHD-EP simulation code. Recently, this code has been applied to Heliotron J, and an experimentally observed n/m=2/4 global Alfvén eigenmode (GAE) was reproduced[5]. The EP-driven instabilities and the EP confinement in the currentless low beta plasmas are analyzed for the three main magnetic configurations of Heliotron J: low (ϵ_{01}=0.01), medium (ϵ_{01}=0.06) and high (ϵ_{01}=0.15) bumpiness configurations, where ϵ_{01} is the ratio between bumpy and DC magnetic components. Based on a CX-NPA measurement[3], EP confinement is improved in the medium and high bumpiness configurations.

The simulation results show that the n/m=2/4 GAE is a dominant mode for all the magnetic configurations. An n/m=1/2 GAE and a 3/5 EPM are observed as recessive components. The n/m=3/5 mode has not yet been experimentally identified, because its frequency and radial location are close to those of the n/m=2/4 GAE. The n/m = 1/2 and 3/5 modes are weak in the low and medium bumpiness configurations, but stronger in the high bumpiness configuration. These modes have a global structure; therefore, EPs in the core region with sufficiently large orbit width can interact with these modes. This causes EP spatial redistribution (transport) from the core to the peripheral plasma. The linear growth rate for the n/m=2/4 GAE is highest for the low bumpiness configuration (See Fig 1). It is reduced for the medium and high bumpiness configurations. This is due to the increase in the magnetic shear by finite beta effect. For the interaction between EP and shear Alfvén wave, EP redistributions in velocity space have revealed that the majority of the resonances were intermediated by the toroidicity of the magnetic field. It also shows that the interactions between high velocity EP and n/m=2/4 GAE are weaker in the medium and high bumpiness configurations.

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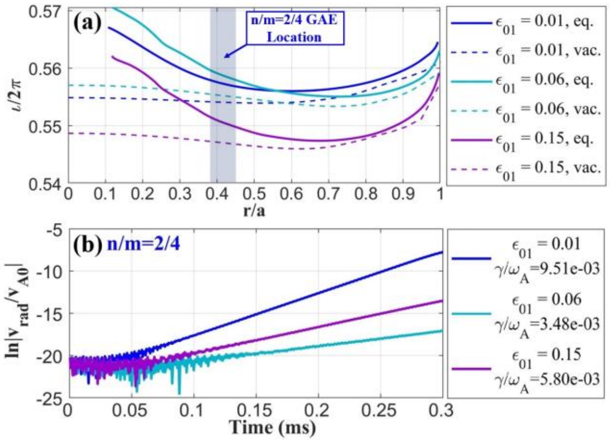

Figure 1: (a) Comparison of $\iota/2\pi$ profiles and (b) logarithmic time evolution of the radial velocity amplitude for n/m=2/4 GAE between low, medium and high bumpiness configurations. In (a), “eq.” and “vac.” denote “equilibrium” and “vacuum”, respectively.

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