§4. Simulation Study of A New Kind of Energetic Particle Driven Geodesic Acoustic Mode

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A new kind of energetic particle driven geodesic acoustic mode (EGAM), which has weak bulk plasma temperature dependence of frequency, has been found in the Large Helical Device (LHD) experiments [1-2]. In this work, the new kind of EGAM is investigated with a hybrid simulation code for energetic particles and magnetohydrodynamics (MHD). It is demonstrated in Fig. 1 that the new EGAM in the simulation results has weak bulk plasma temperature dependence of frequency, which is in contrast to the traditional EGAM whose frequency is proportional to the square root of bulk plasma temperature. Three conditions are found to be important for the transition from the traditional EGAM to the new EGAM: 1) energetic particle pressure substantially higher than the bulk plasma pressure, 2) charge exchange time sufficiently shorter than the slowing down time to create a bump-on-tail type distribution, and 3) bulk plasma density is low enough.

MEGA code is used to simulate the EGAMs in LHD. Since the kinetic geodesic acoustic mode frequency in LHD is close to that in tokamaks, we investigate tokamak type equilibria with concentric circular magnetic surfaces, and with the safety factor profiles and the aspect ratio similar to the LHD plasmas. The energetic-particle distribution function is characterized by the slowing down time τ_s (=8s in this work) and charge exchange time $\tau_{cx}(v)$. $\tau_{cx}(v)=A_1v^7$ for new EGAM and $\tau_{cx}(v)=A_2v^6$ for traditional EGAM, where A_1 and A_2 are constant coefficients. For $\tau_{cx}(v_{NBI})$ shorter than 1s, the distribution function has a bump-on-tail shape. The energetic ion inertia term is added into the MHD momentum equation to simulate with energetic particle density comparable to the bulk plasma density. In addition, a Gaussian-type pitch angle distribution is assumed for the energetic ions.

Both the new and traditional EGAMs are reproduced with simulation parameters based on the LHD experiment [1-2], as shown in Fig. 1. The parameters are magnetic field strength B=1.5T, NBI energy E_{NBI}=170keV, energetic particle beta value β_h=3%, and $\tau_{cx}(v_{NBI})$=0.39s. For electron density $n_e=10^{18}m^{-3}$, the new EGAM has weak bulk plasma temperature dependence of frequency. On the other hand, for electron density $n_e=2\times10^{18}m^{-3}$, the traditional EGAM is excited with the frequency proportional to the square root of bulk plasma temperature. The simulated phenomena are very similar to the experimental observation in Ref. [1-2].

Linear growth properties of the new EGAM are further investigated. The new EGAM frequency increases as the central value of the Gaussian pitch angle distribution decreases, where smaller pitch angle variable corresponds to higher parallel velocity and higher transit frequency. This indicates that the frequency of new EGAM is significantly affected by the energetic particle transit frequency, and the new EGAM is a kind of energetic particle mode (EPM) whose frequency is determined by the energetic particles. In addition, the new EGAM frequency and growth rate depend on β_h and τ_{cx}. Growth rate of new EGAM increases as β_h increases similarly with other energetic particle driven instabilities, but the frequency increases as β_h increases. For higher β_h, the effect of energetic particles is enhanced to make the frequency closer to the energetic-particle transit frequency. In addition, shorter τ_{cx} causes higher growth rate and frequency, because more particles exist in the high-energy region of phase space.

The resonance condition of new EGAM is found to be $\omega_{EGAM}=(l/K)\omega_\theta$, where l and K are arbitrary integers, and ω_θ is the particle frequency of poloidal motion. For confirmation, the particle that resonates strongest with mode is investigated as shown in Fig. 2. The particle circulates 3 times while the mode oscillates 2 times in the time interval between the 2 black lines. This indicates l/K=2/3.

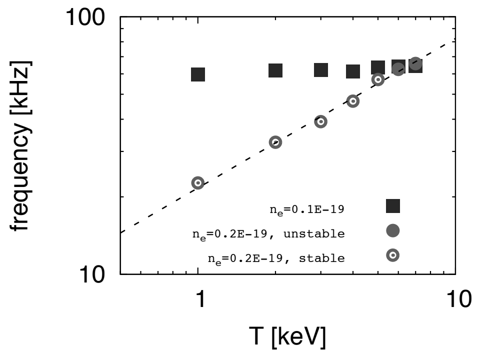

Fig. 1. Two kinds of EGAMs are simulated with β_h =3% and τ_{cx}=0.39s. The bulk plasma densities for new (squares) and traditional EGAMs (circles) are $10^{18}m^{-3}$ and $2\times10^{18}m^{-3}$, respectively. The open circles represent stable mode.

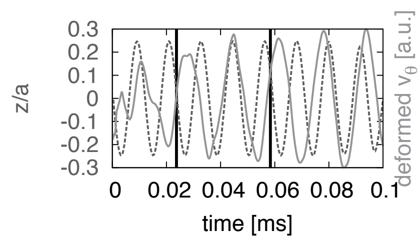

Fig. 2. Time evolution of particle position in z direction (dashed) and v_θ with amplitude deformed to be constant (solid) for the strongest resonant particle.

1) Osakabe, M. et al: 13th IAEA-TM EP, 17-20 September 2013, Beijing, China.
2) Ido, T. et al: 24th IAEA-FEC, 8-13 October 2012, San Diego, USA.