18PB-009

Simulation Study of A New Kind of Energetic Particle Driven Geodesic Acoustic Mode in LHD

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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 and reproduced by MEGA code. Three conditions are important to excite the new EGAM: high energetic particle pressure, short charge exchange time, and low bulk plasma density. A new resonance condition that EGAM frequency $\omega_{EGAM} = (l/K)\times\omega_\theta$ is obtained, where l and K are arbitrary integers and ω_θ is particle poloidal transit frequency. Also, the new EGAM is a kind of energetic particle driven mode (EPM).

1. Introduction

Geodesic acoustic mode (GAM) is an oscillatory zonal flow coupled with density and pressure perturbations in toroidal plasmas. Recently, energetic particle driven GAM (EGAM) is observed in JET, DIII-D, LHD and HL-2A. Theoretical studies have been made by various theorists on the fast excitation due to the loss boundary in pitch angle, on the coupling to the GAM continuum, on the nonlinear second harmonics of EGAM, and on the energy channeling from energetic particles to thermal ions through EGAM. In addition, simulation studies have been made on the linear properties, on the frequency chirping, and on the impact on turbulent transport. In the DIII-D experiment, drops in neutron emission follow the EGAM bursts suggesting beam ion losses. Understanding EGAM is important for magnetic confinement fusion where the energetic particles need to be well confined for the bulk plasma heating.

According to Fu's theory, the EGAMs frequency can be either higher or lower than the conventional GAM frequency [1]. However, only one branch whose frequency is low has been studied for global mode, which we call traditional EGAM, until a new kind of EGAM was observed in LHD as shown in Fig. 1(a). By contrast of the traditional EGAM (circle) whose frequency is proportional to the square root of bulk plasma temperature and lower than the conventional GAM frequency, the new EGAM (square) is quite remarkable. It has weak bulk plasma temperature dependence of frequency, and frequency is higher than the conventional GAM frequency. Since the theory and simulation study for the excitation of the new EGAM has not been made yet, we will try to clarify the excitation conditions of the new EGAM and transition from traditional EGAM to new EGAM, then investigate the new EGAM resonance condition in this paper.

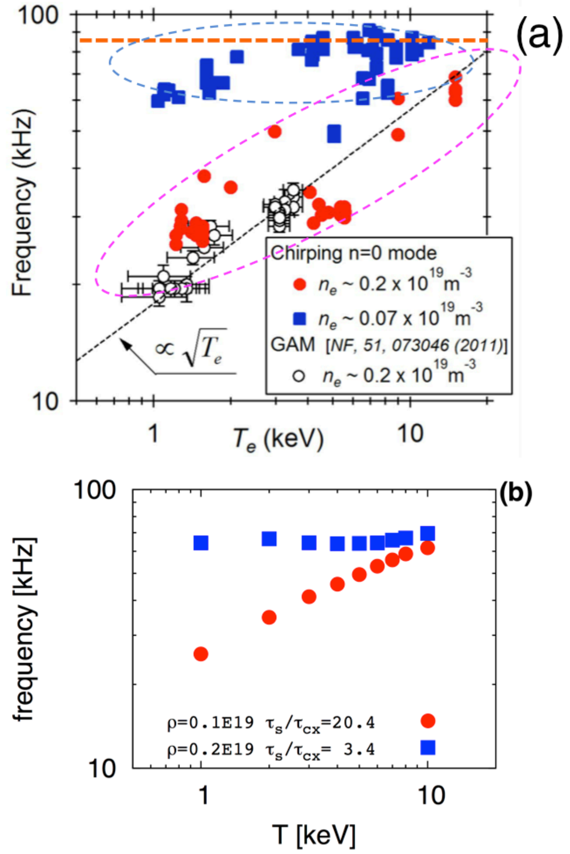

Fig.1. New (square) and traditional (circle) EGAMs in (a) LHD experiment [2,3] and (b) simulation.

2. Simulation Model and Method

A hybrid simulation code for energetic particles interacting with a magnetohydrodynamic (MHD) fluid, MEGA, is used for the simulation of both the traditional and new EGAMs. In the MEGA code, the bulk plasma is described by the nonlinear MHD equations. The drift kinetic description and the δf particle method are applied to the energetic particles. For new EGAM simulation, velocity distribution f(v) is slowing down with charge exchange $f(v)=C\times(v^3+v_c^3)^r$ and $r=\tau_s/(3\tau_{cx})-1$, where C is integration constant, v_c is the critical velocity, τ_s is slowing down time, and τ_{cx} is charge exchange time. Pitch angle distribution is Gaussian type. The energetic particle inertia term is added into the MHD momentum equation.

3. Simulation Results

Both the traditional and new EGAMs in LHD are reproduced in Fig. 1(b). The simulated phenomena are very similar to the experimental observation that is shown in Fig. 1(a). To investigate the transition from traditional EGAM to new EGAM, the mode frequency dependence on τ_{cx}, energetic particle pressure β_h, and bulk density are investigated. The frequency decreases with τ_{cx} increases, because shorter τ_{cx} value means more energetic particles distribute in the high-energy region in phase space. In addition, frequency increases with β_h increases, which means that the energetic particle contributes positively to the mode frequency. Finally, frequency increases with bulk density decreases. Since we can identify the low frequency mode as traditional EGAM, and identify the high frequency mode as new EGAM, the conditions of new EGAM excitation are short τ_{cx}, high β_h and low bulk density.

Normally, when a resonant particle passes one round in the poloidal angle, the phase of the mode should change by a multiple of 2π, thus, the resonance condition is given by $\omega_{mode}T_\theta-n\Delta\varphi=2\pi l$, where T_θ is the time to pass one round in the poloidal angle, n is the toroidal mode number, $\Delta\varphi$ is the toroidal angle, and l is an arbitrary integer [4]. But the new EGAM case is special. When a resonant particle passes not one round but K rounds in the poloidal angle, the resonance condition is given by $K\omega_{mode}T_\theta-Kn\Delta\varphi=2\pi l$, where K is an arbitrary integer. n=0 for GAM, so the resonance condition is $\omega_{EGAM}=(l/K)\times\omega_\theta$. To confirm the resonance condition, the particle that is counter-going and resonates strongest with mode (that means the particle with maximum δf value) is selected from all the marker particles, and investigated. This particle poloidal transit frequency $\omega_\theta/(2\pi)$=103.4 kHz. The evolution of the particle position in z direction is plotted as the solid curve in Fig. 2. When the particle crosses the mid-plane, the z value becomes 0, and that means the particle moves a half period in poloidal cross-section. We also plot the deformed mode amplitude v_θ as the dashed curve, where deformed v_θ is $v_\theta\times\exp(-\gamma t)$. v_θ increases exponentially with time, but the deformed v_θ does not grow because of $-\gamma$, then we can focus only on the mode period. In Fig. 2, the particle moves 5 circles while mode oscillates 3 times in the interval between the 2 black lines, so l/K=3/5. According to the resonance condition, $\omega_{EGAM}/(2\pi)$ should be 62.0 kHz, that is, very close to the mode frequency 63.9 kHz.

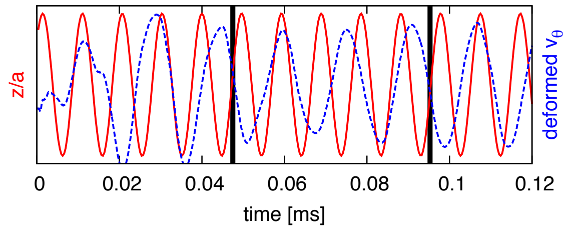

Fig.2. Time evolution of particle position in z direction (solid) and deformed amplitude v_θ (dashed) for the strongest resonant particle in counter-going direction.

In addition, it is found that the mode frequency increases as the central value of the Gaussian pitch angle distribution decreases, where the smaller pitch angle variable corresponds to higher parallel velocity and higher transit frequency. This shows 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.

4. Summary

In summary, we reproduced a new kind of EGAM that has weak bulk plasma temperature dependence of frequency in LHD. The simulation results are consistent with experiments. 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. The resonant particles of new EGAM are also investigated, and a new resonance condition, $\omega_{EGAM} = (l/K)\times\omega_\theta$, is obtained. Finally, the new EGAM frequency is affected by energetic particles indicating that the mode is a kind of typical EPM.

References

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