§2. Linear Properties of Energetic Particle Driven Geodesic Acoustic Mode

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Linear properties of energetic particle driven geodesic acoustic mode (EGAM) have been investigated for the Large Helical Device (LHD) plasmas with a hybrid simulation code for a magnetohydrodynamic (MHD) fluid interacting with energetic particles, MEGA1). Since the kinetic GAM frequency in LHD is close to that in tokamaks2), tokamak type equilibria are examined with concentric magnetic surfaces, and with the safety factor profiles and the aspect ratio similar to the LHD plasmas. The equilibrium energetic particle distribution f_0 is modeled by $f_0(E,\mu,P_\varphi)=G(E)H(\Lambda)I(P_\varphi)$ where E is particle energy, μ is magnetic moment, $\Lambda=\mu B_0/E$ is pitch angle variable, B_0 is magnetic field strength, and P_φ is toroidal angular momentum. The function $G(E)$ is the slowing down distribution and $I(P_\varphi)$ represents the radial distribution which we assume a Gaussian profile in plasma radius. The pitch angle distribution is modeled by $H(\Lambda)=\exp[-(\Lambda-\Lambda_{peak})^2/\Delta\Lambda^2]$ for the energetic ions produced by the neutral beam injection (NBI) in the LHD experiment. As the GAM frequency is sufficiently lower than the beam ion gyro frequency, magnetic moment is an adiabatic invariant. Then the beam ions evolve along $\mu=const.$ curves. Energetic particles in the phase space region $\partial f_0/\partial E>0$ with $\mu=const.$ destabilize the GAM by the inverse Landau damping.

We simulated EGAM using realistic parameters for the LHD experiment, B=1.5T, electron density n_e=10^{18}m^{-3}, electron temperature 4keV at the plasma center, and NBI energy 170keV. The EGAM perturbation frequency and the conventional local GAM frequency are shown as functions of normalized minor radius in Fig. 1. It is found that the EGAM is a global mode because the perturbation frequency is spatially constant, whereas the conventional local GAM frequency constitutes the continuous spectrum that varies depending on the plasma temperature and the safety factor. The frequency of the EGAM intersects with the GAM continuous spectrum. The EGAM frequency vs. the square root of bulk plasma temperature is shown in Fig. 2. We see the frequency is in proportion to the square root of temperature. Figure 3 shows the EGAM frequency and growth rate for different energetic particle beta values. The EGAM frequency is lower and the growth rate is higher for higher energetic particle pressure. This is consistent with the theoretical prediction3). The poloidal mode numbers of poloidal velocity perturbation, plasma density perturbation, and magnetic perturbation are m=0, 1, and 2, respectively. Good agreement is found between the LHD experiment and the simulation result in EGAM frequency and mode numbers. The EGAM spatial profile depends on the energetic particle spatial distribution and the equilibrium magnetic shear. Wider energetic particle spatial profile broadens the EGAM spatial profile. The EGAM spatial profile is wider for the reversed magnetic shear than for the normal shear.

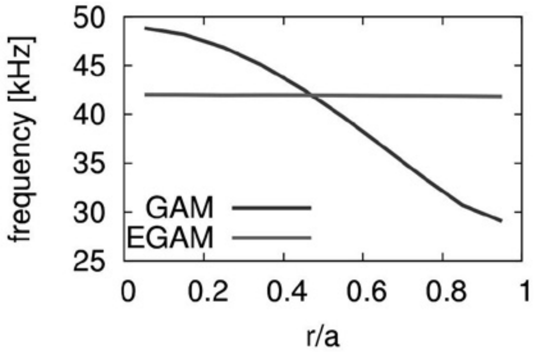

Fig. 1. Frequency profiles of EGAM perturbation and conventional GAM.

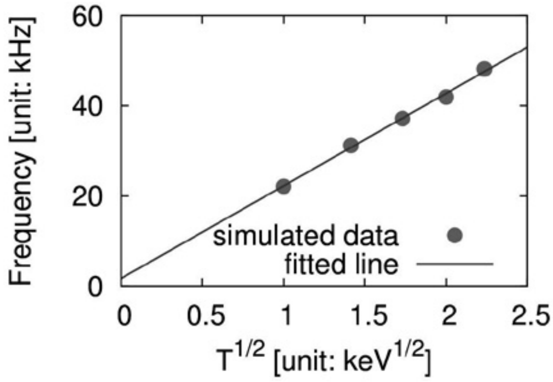

Fig. 2. EGAM frequency vs. square root of bulk plasma temperature. Solid line is a linear fit to the data.

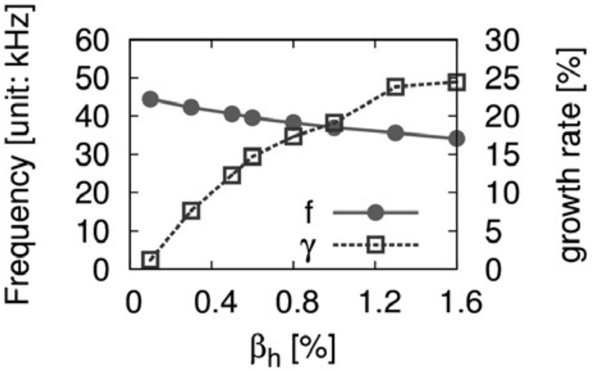

Fig. 3. Frequency and growth rate of EGAM vs. energetic particle beta value at the plasma center.

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2) Sugama, H. and Watanabe, T.-H.: Phys. Plasmas **13** (2006) 012501.
3) Fu, G. Y.: Phys. Rev. Lett. **101** (2008) 185002.