§15. Simulation Studies of GAM Oscillation in Helical Configurations

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Zonal flows and the geodesic acoustic mode (GAM) oscillation in toroidal plasmas have been investigated intensively in the recent fusion research, as it is expected that the zonal flow suppresses microinstabilities and anomalous transport. Recently the analyses of GAMs have been extended for helical configurations by Sugama and Watanabe[1] based on the gyrokinetic model. The analysis showed that the GAM frequency and damping rate strongly depend on the magnetic field spectrum, though the GAM damping rate and comparison with the direct gyrokinetic simulation have been evaluated only in a simple, single-helicity model. The real magnetic field in Large Helical Device(LHD) has a broadened Fourier spectrum of magnetic field if the magnetic axis is shifted inward or outward. The shift of magnetic axis is used to control the neoclassical confinement property of the plasma. Therefore, it is interesting to investigate the behavior of the GAM oscillation in realistic multi-helicity configuration.

We have adopted a neoclassical transport code FORTEC-3D[2], which solves the drift-kinetic equation and time evolution of radial electric field in helical plasmas by the δf method, to study GAMs in LHD plasma. Non-local effect arising from the finiteness of drift widths of ion particle orbits is included in the simulation. In that sense, our study is an extension of the previous research by Novakovskii [3] which investigated the GAM damping in tokamak using a drift-kinetic equation solver on a single flux surface.

We focused on the question how the three-dimensional magnetic configuration affect the GAM oscillation. Three MHD equilibrium configurations which differ only in the major axis position were investigated. The multi-helicity magnetic field is given as

$$B(\rho,\theta,\zeta) = B_{0,0}(\rho) + \sum_{n=0}^{\infty} B_{0,n}(\rho)\cos nN_\phi\zeta + \sum_{m=1}^{\infty}\sum_{n=-\infty}^{+\infty} B_{m,n}(\rho)\cos(m\theta - nN_\phi\zeta).$$

The analytic evaluation of GAM frequency and damping rate shown in [1] in the drift-kinetic limit, i. e., $T_e/T_i \to 0$ are as follows

$$\frac{\omega_G^2}{\omega_0^2} \simeq \frac{q_*^2}{q^2}\left(1+\frac{46}{49q_*^2}\right) \Big/ \left[1+\frac{q_*^2}{2}\sum_m \frac{m^2 c_{m,\pm1}^2}{(m\mp qN_\phi)^2}\right],$$

$$\frac{\gamma}{\omega_0} \simeq q\sqrt{\frac{\pi}{7}}\frac{q_*^2}{q^2}\left[(\hat\omega_G^2+\hat\omega_G^4)e^{-\hat\omega_G^2} + \sum_m \frac{m^2 c_{m,\pm1}^2}{2|m\mp qN_\phi|}\times \left(1+\frac{\hat\omega_G^2}{(m-qN_\phi)^2}\right)\right] \Big/ \left[1+\frac{46}{49q_*^2}+\frac{q_*^2}{2}\sum_m\frac{m^2c_{m,\pm n}^2}{(m\mp qN_\phi)^2}\right],$$

where $\omega_0 = \sqrt{7}v_{Ti}/2R_{ax}$ is a rough estimation of GAM real frequency for tokamak, $c_{m,n} = B_{m,n}/B_{1,0}$, $\hat\omega_G = \omega_G(qR_{ax}/v_{Ti})$, $q_*/q = R_{ax}B_{1,0}/\bar r B_{0,0}$ and $q = \iota^{-1}$, respectively. In the definition of q_*, the effective minor radius is defined as $\bar r = \rho a$, where $a = \sqrt{\psi_a/B_0}$. To check the effect of each component, the number of Fourier components used in the simulation were varied. The simulation results are plotted in Figure 1. Analytic estimation are also shown. The real frequency has weak dependence on the number of Fourier modes and decreases as the magnetic axis is shifted inward. This is mainly because of the change of q_*/q, which represents the change of toroidicity according to the axis shift. Then the smaller ω_G makes the damping rate of GAM γ higher for inward-shifted configuration. Physical explanation is that for smaller ω_g, the population of passing particles resonating with GAM becomes larger. The effect of broadened spectrum can be seen on the outer flux surface in $R_{ax} = 3.52$ case, where γ grows as the number of Fourier modes. The difference between analytic estimation and FORTEC-3D simulation is mainly because of the large-aspect-ratio approximation and because only $n = \pm1$ sidebands are included in the formula.

Thus it was shown that the GAM frequency and the damping rate can be controlled by the axis shift in LHD plasma.

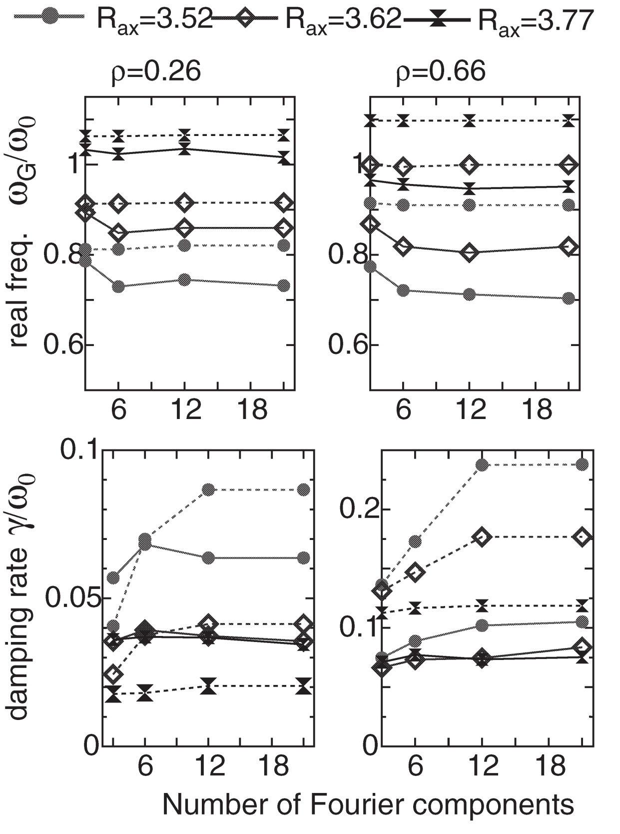

Fig. 1: GAM frequency and damping rate on two flux surfaces. Solid lines are FORTEC-3D simulation results and dottted lines are estimations from analytic formula.

1) Sugama, H. and Watanabe, T.-H., Phys. Plasmas **13** (2006) 012501

2) Satake, S. *et al*, Nucl. Fusion **45** (2005) 1362

3) Novakovskii, S. V. *et al*, Phys. Plasmas **4** (1997))4272