§4. Gyrokinetic Simulations for Ion Temperature Gradient Mode and Zonal Flows in LHD High Ion Temperature Discharge

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In recent LHD experiments, high ion temperature (high-T_i) discharges have been realized by the high power neutral beam injection, and the spatial distributions of the density fluctuations have been also measured by the two-dimensional phase contrast imaging. In the measurements in the shot number 88343 [1, 2], the large-amplitude fluctuations observed in the plasma frame, propagates in the direction of the ion diamagnetic rotation and the amplitude increases as the ion temperature gradient increases. The peak of the fluctuation amplitude is found at region of $\rho \sim 0.6$-0.8 in the radial space, and $k\rho_{ti} \sim 0.45$ in the perpendicular wavenumber space, where ρ is the normalized minor radius and ρ_{ti} is the ion thermal gyroradius. These facts of the observations seem to show the features of the ion temperature gradient modes (ITG modes), therefore, the fluctuations observed in the experiment are considered to be driven by the ITG modes.

We performed the linear gyrokinetic Vlasov simulations [3] for the ITG modes and zonal flows for the high-T_i discharges, utilizing GKV-X code [4] under the experimental conditions of density, temperature, and VMEC equilibrium configuration in the discharge, with the assumptions of $n_i/n_e = 1$, $T_i/T_e = 1$, collisionless, adiabatic electrons, and zero-beta limit. The simulation results show that the ITG mode in the configuration is most unstable at $\rho = 0.65$ in radial space (see Fig. 1), and $k_y\rho_{ti} = 0.35$ in the space of the poloidal wavenumber k_y. Comparing the results with the fluctuation measurements in the LHD discharge, it is found that the regions of the experimental fluctuation peaks are located around the positions where the linear ITG modes are most unstable in radial and wavenumber spaces. Then, taking account of the error-bars of the experimental data, we thought that the density fluctuations observed in the LHD experiments are attributed to the ITG modes.

To find the critical ion temperature gradient for the ITG mode in the high-T_i discharge, we investigate the dependence of the ITG mode growth rates on the temperature gradient. Then, we obtain the critical values of R_0/L_{Ti} where the growth rate vanishes. Figure 2 shows the critical values for the high-T_i phase, as a function of ρ. From the plot, we find that γ_{max} given by Fig. 1 peaks at a radial position where the deviation of the temperature gradient from the critical value is largest. The critical value is higher than the experimental value for $\rho \lesssim 0.2$ where γ_{max} of Fig. 1 vanishes.

The linear response of the zonal flow potential in the configuration is also investigated. In the investigations, it is observed that the damping of the geodesic acoustic mode (GAM) oscillations in the lower safety factor is faster than those in the higher one. The evolution of the GAM-averaged response kernel shows that the initial behavior does not change for different perpendicular wavenumbers, but is influenced by the equilibrium configuration. The residual levels are enhanced by increasing the radial wavenumber and are also influenced by the helical Fourier components which depend on the radial position and the T_i profile. These results are consistent with the analytical conclusions for the zonal flow responses [5].

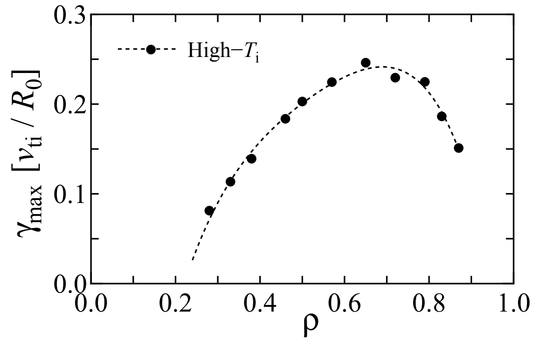

Fig. 1: Radial profile of the growth rate of the ITG mode for the LHD high-T_i discharge.

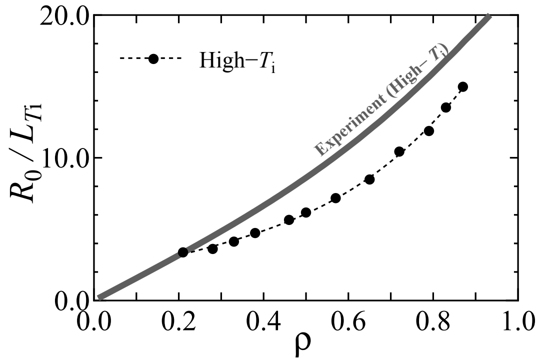

Fig. 2: Radial profile of the critical ion temperature gradient obtained by GKV-X simulations (black circles), and the bold curve represents the experimental profile of R_0/L_{Ti} in the LHD high-T_i discharge.

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