# §21. Linear Characteristics of Turbulence under Heating Power Scan in LHD

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The linear characteristics of turbulence under heating power scan [1] was studied in LHD by using local flux tube gyrokinetic code GS2[2] taking into account the LHD three-dimensional magnetic configuration. Analysis was done for two kinetic species (electron and hydrogen ion). Hydrogen density ($n_H$) and electron density ($n_e$) was estimated separately from the measurements of $n_e$, $n_H/(n_H+n_{He})$ and $n_c^{6+}$, where $n_e$ is electron density, $n_{He}$ is $He^{2+}$ density and $n_c^{6+}$ is $C^{6+}$ density. Collisionality between all the charged particles are taken into account. The electromagnetic effects are not included and based on electro static approximation, The gyrokinetic linear analysis was done for $k\rho_i$=0.1-3, where ion temperature gradient mode (ITG) and trapped electron mode (TEM) are dominant instabilities.

Figure 1 shows profile of two different timing of ref.1. The timing at t=4.1sec is the phase 2 in ref.1. At this timing, the heating was by on axis EC and perpendicular injected positive ion based NB (P-NB). The timing at t=4.433sec is the phase 3 in ref.1 and the heating is by only P-NB. The linear characteristics are studied at ρ=reff/a99=0.5 and 0.85. The former location corresponds to the peak position of inner mode, the latter to the peak position of outer mode [1].

The change of the heating power results in change of profiles as shown in Fig.1. From t=4.1sec to 4.433sec, $n_H$ decreases. $T_e$ decreases. $T_i$ increases. Temperature ratio ($T_e/T_i$) increases. The electron ion collisionality ($\nu_{ei}$) increases. The normalized $n_H$ gradient stays almost constant. The normalized $T_e$ gradient decrease at ρ=0.5 stays constant at ρ=0.85. The normalized $T_i$ gradient increases at ρ=0.5 and decreases at ρ=0.85.

Figure2 shows linear spectrum at ρ=0.5 and ρ=0.85. At ρ=0.5 (inner mode location), whole calculation region was unstable and the linear growth rate (γ) becomes larger at higher $k\rho_i$. The real frequency ($\omega_r$) is ion diamagnetic direction at $k\rho_i$ <0.4, and electron diamagnetic direction at $k\rho_i$ >0.5. On the other hands, the experimental $k\rho_i$ is 0.6, which is much lower than higher unstable region suggesting inversely cascading of turbulence energy toward low $k\rho_i$. The propagation direction of the measured turbulence is close to $V_{ErxB}$ suggesting real frequency is close to zero[1]. The inner mode disappears after turning off of EC at t=4.433sec. At this timing, whole calculation region becomes stable. This is consistent with disappearance of the inner mode at this location. The stabilizing term of inner mode can be considered from the change of the profiles shown in Fig.1. As shown in Fig.1 (f) and (g), from t=4.1 to t=4.433s, the normalized $T_e$ gradient decreases, and collisionality increases at ρ=0.5. Thus, the disappearance of the inner mode is likely to be stabilization of temperature driven trapped electron mode (TEM).

At ρ=0.85 (outer mode location), the unstable region exists at $k\rho_i$<0.6 and $k\rho_i$>1.0 at t=4.1sec. At this timing, the γ is higher at $k\rho_i$<0.6 than at $k\rho_i$>1.0. This is different spectrum at ρ=0.5, where γ becomes higher at higher $k\rho_i$. The real frequency was electron diamagnetic direction except at $k\rho_i$ =0.6, where $\omega_r$ is almost zero. At t=4.433sec, the unstable region becomes only at $k\rho_i$ <0.8. the growth rate decreases and $\omega_r$ is around zero frequency. On the other hands, the measured $k\rho_i$ was around 0.3 at t=4.1 and 4.433sec is close to the value at peak of γ. The propagation direction of the measured turbulence is ion diamagnetic direction at both timing suggesting real frequency is ion diamagnetic direction. The outer modes survives after turning off of EC at t=4.443s. As shown in Fig.1 (e)-(g) change of the normalized gradients of $n_H$, $T_e$ and $T_i$ are relatively small at ρ=0.85. The increase of $\nu_{ei}$ and decrease of $T_e/T_i$ are key parameter. Although $\nu_{ei}$ stabilize both ITG and TEM, but its effects is smaller on ITG. Also, reduction of $T_e/T_i$ results in mode switching for TEM and ITG. These suggest that outer mode switch from TEM to ITG or from ITG/TEM to deep ITG.

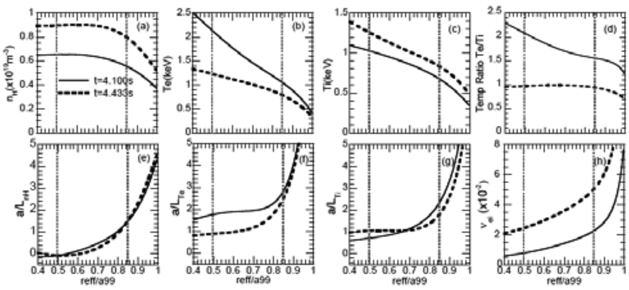


Fig.1 Profiles of two timings at t=4.1s and t=4.433s of the discharge in ref.1. The calculation locations (ρ=reff/a99=0.5 and 0.85) are shown by dashed lines.

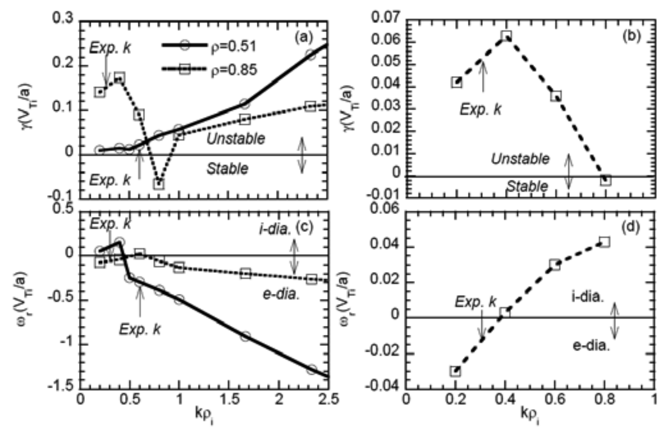


Fig.2 Comparison of linear spectrum at t=4.1sec (a), (c) and t=4.433sec (b), (d)

1) Tanaka. K., et al, this report, "Turbulence response under temperature ratio and collisionality scan"
2) Dorland ,W., et al., Phys. Rev. Lett. 85, 5579 (2000)