§6. Confinement Degradation and Turbulent Fluctuation in High β Regime of LHD

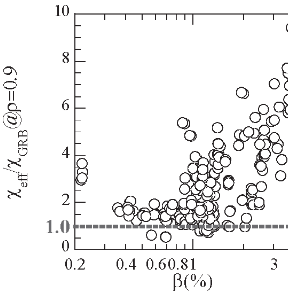
Tanaka, K., Watanabe, K.Y., Funaba, H., Michael, C.A. (JSPS Fellow)

It is required to operate fusion reactor more than 5% of volume averaged β (<β>) in order to make the fusion reactor cost attractive. In LHD, a five percent <β> was achieved at B_t (toroidal magnetic field) = 0.5 T in the 10th cycle experimental campaign [1]. The operation at high β regime should be coinciding with good confinement characteristics. The recent global energy confinement scaling in stellarator/heliotron device (ISS04) shows weak β dependence, energy confinement time (τ_e) is proportional to $\beta^{-0.19}$[2]. However, detail confinement characteristic was not yet understood in high β regime.

Systematic power balance analysis was done in the wide range of <β> (0.2~3.9%) The international stellarator scaling 2004 shows weak gryo-Bohm character [2]. The Gyro-Bohm scaling shows τ_e is proportional to ρ^{*-1}, where ρ* is ion Larmor radius normalized by averaged minor radius, and thermal conductivity is proportional to $\rho^* D_{Bohm} \sim \rho^* T_e/(aB_t)$, where D_{Bohm} is Bohm diffusion coefficient, a is averaged minor radius. For the investigation of discrepancy from ISS04 in high beta regime, normalized χ_{eff} by $\rho^* T_e/(aB_t)^2$ was compared with <β>. The normalized χ_{eff} at ρ =0.9 was used. This is because of two reasons. Firstly, the edge thermal conductivity strongly influences global energy confinement. Then secondly a possible instability in high beta regime is resistive interchange and it localizes in the plasma edge region.

As shown in Fig.1, the normalized χ_{eff} is around unity at <β> less than 1%. This indicates edge energy transport is Gyro-Bohm character, which is predicted by ISS04. However, enhanced normalized χ_{eff} is clearly observed at <β> more than 1%. This indicates confinement is degraded at high <β> more than expectation of ISS04. The turbulent fluctuation was measured by Far Infrared (FIR) laser interferometer. Figure 2 shows amplitude spectrum of electron density measured. The FIR interferometer measures line integrated fluctuation. Since the beam size is around 5cm, signal is dominated by the fluctuation, of which wavelength is longer than 5cm. As shown in Fig.2, signal (>1kHz) is noise level at <β> is 0.5%, but the signal more than noise level extends to 50kHz at <β> is 2.9%. The signal is from the chord, which passes through around vacuum plasma axis. The edge chord if interferometer may be appropriate to investigate resistive interchange turbulence, which localizes in the edge. However, plasma edge shifts with increase of beta die to Shavranov shifts, then, the relative comparison in the low and high beta is influenced by the shifting. For the comparison in the wide range of beta, we selected the central chord, which is insensitive to the Shavranov shift.

Figure 3 is comparison with fluctuation level and <β>. The fluctuation level was defined as a ratio of fluctuation amplitude excluding noise amplitude to line density. As shown in Fig.3, the fluctuation level clearly increases with increase of <β> at <β> larger than 1%. This is very close tendency observed in Fig.1. These results suggest turbulence measured by FIR interferometer cause confinement degradation at high beta regime. The fluctuation measured by the FIR interferometer is longer wavelength compared with drift wave turbulence such as ion temperature gradient mode or trapped electron mode, of which wavelength is order of ion Larmor radius. Such a small scale turbulence was measured by CO_2 laser phase contrast imaging, and its edge fluctuation level increases with increase of edge particle diffusion coefficient, [3] in low beta regime (<β> less than 1%). This suggests that the peak of perpendicular wavenumber (k_{perp}), which play essential role on transport is smaller ($k_{perp}\ \rho_i$<<1) in high beta and larger ($k_{perp}\ \rho_i$~1) in low beta.



Fig,1 Relation between normalized χ_{eff} and <β>

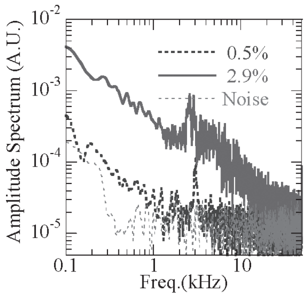


Fig.2 Amplitude spectrum of electron density at different< β>

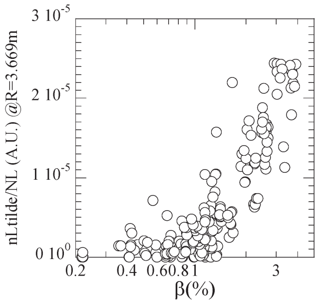


Fig.3 Relation between fluctuation level and <β>

References
1) Watanabe, K.Y., Sakakibara, S. et al., in this annual report
2) Yamada, H., Nucl. Fusion **45**, 1684 (2005)
3) Tanaka, K., Fusion Sci. **51**, 97 (2007)