§2. Comparison of Intrinsic Toroidal Rotation with Different Confinement Regimes

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Intrinsic toroidal rotation attracts much attention because toroidal rotation has a potential to control MHD stability in high beta plasmas. Empirical scaling law is obtained for H-mode plasmas of tokamaks [1]. However, intrinsic rotations in L-mode plasmas depends on plasma parameters in a complicated way, and is considered that they are determined by turbulence [2]. In helical plasmas, an anomalous perpendicular viscosity due to turbulence and a parallel viscosity play an main role to determine toroidal rotation in the core and periphery, respectively. The intrinsic rotations were observed to correlate with ion temperature gradient and radial electric field at the peripheral region ($r_{\rm eff}/a_{99} \sim 0.8$)[3]. It seems to be consistent with neoclassical effects of off-diagonal terms of transport matrix, while the quantitative comparison with neoclassical calculations was not done yet. In this study, we focus on the intrinsic rotations in different confinement states in the core region of LHD plasmas, where turbulence is considered to determine both perpendicular viscosity and intrinsic drive of toroidal rotation.

Significant co-directed intrinsic rotation was observed with ion internal transport barrier (ion ITB) formation in the core of LHD plasma, and it correlates with ion temperature gradient [4, 5]. Figure 1 shows the flux-gradient relation of toroidal momentum transport with ion ITB, and significant asymmetry between co-directed and ctr-directed rotations indicates the intrinsic rotation in the co-direction. The neoclassical effect on the intrinsic rotation is much smaller than the asymmetry in the flux-gradient relation, and can not explain the experimentally estimated intrinsic rotation.

On the other hand, intrinsic rotation in the counter-direction was observed in the perpendicular NBI heated plasma, in which any confinement improvement was not observed. Figure 2 shows the toroidal rotation profile of perpendicular NBI heated plasma. There are no external torque input, thus the observed rotation is the intrinsic rotation. This rotation is not explained by the neoclassical effect.

The quantitative comparison of experimental observation of intrinsic rotation and non-diffusive term effects of neoclassical transport without external torque became possible due to recent progress of numerical code development. In the case of tangentail NBI injection (external torque input), Ida and Nakajima formula is useful to analyze toroidal momentum balance and the contribution of neoclassical transport. In this study, experimental observation of intrinsic rotation in the core plasma can not be explained by neoclassical effect, indicating they are determined by turbulence. The co- and counter-directed intrinsic rotations were observed in the different confinement regimes. In order to understand the mechanism of turbulence driven intrinsic rotation, comparison between fluctuation measurement and intrinsic toroidal rotation is necessary, which is left for future study.

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4) K. Nagaoka, et al., Nucl. Fusion **51**, (2011) 083022.

5) K. Ida, et al., Nuclear Fusion **50**, (2010) 064007.

6) S. Satake, et al., Plasma Phys. Control. Fusion, **53**, (2011) 054018.

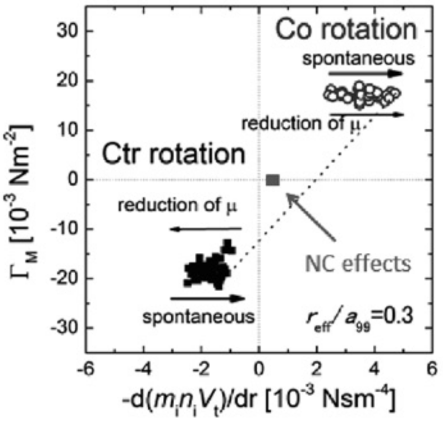

Fig. 1: Flux-gradinet relation of momentum transport in the core region of ion ITB plasma. Offset (asymmetry) between co- and ctr-driven cases indicates the co-directed intrinsic rotation.

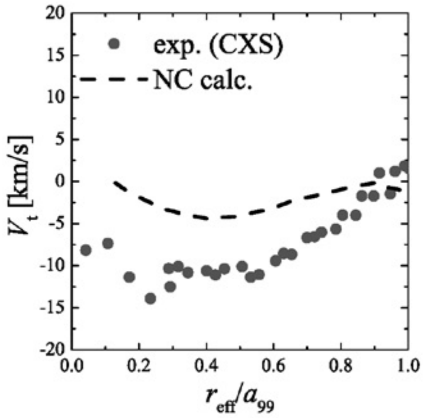

Fig. 2: Toroidal rotation profile of perpendicular NBI heated plasma (no external torque input). The neoclassical toroidal roation was calculated with FORTEC3D code [6].