§10. Simulation and Comparison with Experiment of Neoclassical Viscosity in JT-60U and LHD

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Neoclassical toroidal and poloidal viscosities (NTV, NPV) are the fundamental physics which act as damping force of plasma toroidal/poloidal rotation. Since the origin of neoclassical viscosity is anisotropy of magnetic field strength and that in perpendicular and parallel pressure, $p_\perp - p_\parallel$, precise drift-kinetic simulation is required to evaluate NTV and NPV in 3D configurations. We have developed and applied FORTEC-3D[1] drift-kinetic code to evaluate the neoclassical viscosity.

i) NTV in JT-60U In the past JT-60U experiments, ferritic steel tiles (FSTs) have been inserted to the vacuum vessel to reduce the toroidal magnetic ripples and to investigate the effect of toroidal ripples to the toroidal rotation speed. In JAEA, an integrated transport analysis suite, TOPICS code[2], has been developed, which solves momentum balance equation and self-consistent radial electric field profile, including the effect of the collisional and $j \times B$ torques from fast ions by NBIs. Following the research in 2013, we investigated the effect of the NTV torque on the toroidal rotation by combining TOPICS and FORTEC-3D codes. Co-, counter- and balance NBI discharge cases were tested. Fig.1 shows the results for the cases without FSTs, In each case, result with including the NTV effect reproduces the observed toroidal rotation more correctly. On the other hand, for the cases with FSTs (no figure), it is found that the rotation profile does not change by including the NTV effect. In conclusion, the combined simulation has successfully demonstrated the quantitative reliability for the estimation of toroidal rotation by including the NTV effect.[3]

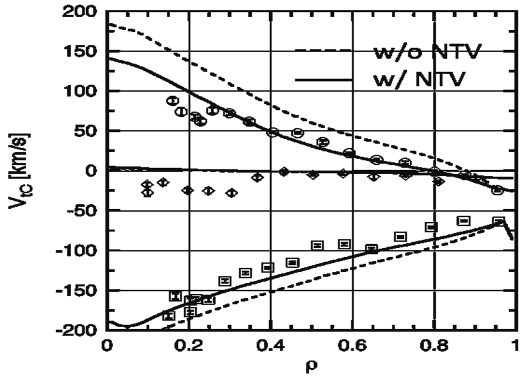

Fig. 1: Toroidal rotation profiles in Co-, counter-, balance NBI discharges in JT-60U, before installing FSTs. Lines represents TOPICS simulations with or without including NTV, and points represents observed values.

ii) NPV in LHD Effect of external magnetic field perturbation is also investigated in LHD. Recent experimental study[4] has revealed that the threshold amplitude of $m/n = 1/1$ RMP field to penetrate into plasma and create island at $\iota = 1$ surface depends on the magnetic axis position, R_{ax}. Since it is theoretically predicted that the NPV in LHD decrease as R_{ax} decreases from 3.75m, and the threshold RMP amplitude also decreases with R_{ax}, a hypothesis is that the NPV mainly determines the threshold amplitude[5]. To understand the dependence of NPV in real discharges, we evaluated NPV about 15 different LHD shots using FORTEC-3D. As shown in Fig. 2, NPV amplitude is basically found to increase with R_{ax} but some exceptions. In reality, NPV also depends on the radial electric field, and the simulation study revealed that evaluation of NPV with solving the ambipolar-E_r is also important to explain the dependence of NPV. The simulation study also found that the RMP field applied in LHD experiment is to weak to affect the NPV. Different from NTV in tokamaks, NPV in LHD is already very strong without external magnetic perturbation. This reinforces the hypothesis that the threshold RMP amplitude is determined by NPV evaluated without considering the RMP effect.

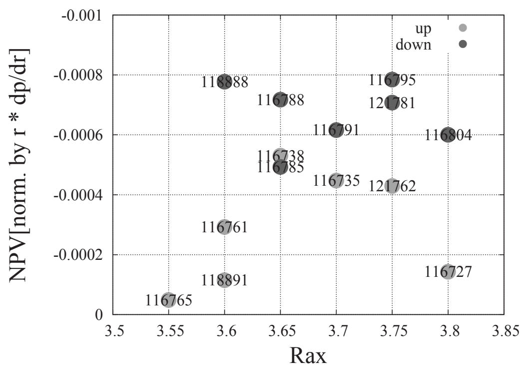

Fig. 2: Dependence of NPV on R_{ax} position in LHD discharges."up" and "down" mean the timing during RMP amplitude was rampig up or down.

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

2) Honda M. *et al.*, Comput. Phys. Commun. vol.181 (2010) 1490.

3) Honda M., Satake S. *et al.*, 25th IAEA Fusion Energy Conf., TH/5-1 (2014)

4) Narushima Y. *et al.*, 25th IAEA Fusion Energy Conf., EX/P6-35 (2014)

5) Nishimura S. *et al.*, Plasma Fus. Res. vol.5 (2010) 0404