§18. Integrated Simulation of Neoclassical Toroidal Viscosity and Rotation in Tokamaks

Satake, S., Suzuki, Y., Honda, M. (JAEA),
Matsuoka, S. (RIST)

Neoclassical toroidal viscosity (NTV) is a fundamental physics which acts as one of the damping forces of plasma toroidal rotation. Even though tokamak devices are ideally constructed to be toroidal symmetric, there always exists weak anisotropy in the magnetic field strength of tokamak in toroidal directions. Such toroidal ripples are caused either by the discrete toroidal field coils, error in construction of the coil, or ferritic materials installed near the vacuum vessels, and broken toroidal symmetry give rises to NTV.

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[1]. It was found that the change in toroidal rotation profile in tangential-NBI plasmas before and after inserting FSTs could not be explained only from the effect of toroidal field ripples on NBI torques[2]. Therefore, it is expected that the NTV on bulk ions plays an important role in the determination of toroidal rotation profile.

In JAEA, an integrated transport analysis suite, TOPICS code[3,4], 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. In 2013, we developed an integrated simulation method to include the NTV torque on bulk ions, which is evaluated by another neoclassical transport code, into the momentum balance equation in TOPICS code. For this purpose FORTEC-3D code [5], which solves the drift-kinetic equation in 3-dimensional magnetic configuration, is incorporated with TOPICS to evaluate the NTV caused by toroidal field ripples. FORTEC-3D code was extended so that it can treat the up-down asymmetric single-null configuration of JT-60U. 3-dimensional magnetic field configuration with weak broken toroidal symmetry are reconstructed using VMEC code by taking account of the perturbation of FSTs and real geometry of toroidal field coils. The amplitude of the magnetic ripples is reduced from 1.6% to 0.8% of the main toroidal field, by inserting the FSTs.

Figure 1 shows the profiles of toroidal torques. By inserting the FSTs, the peak amplitude of NTV torque reduced almost half according to the reduction of magnetic ripples. On the other hand, torque from NBI is affected little by FSTs. Figure 2 shows the toroidal rotation profile solved by TOPICS. It is found that 1) The measured V_ϕ increased about twice after inserting the FSTs, 2) Including the NTV torque significantly changes the expected toroidal rotation from the momentum balance, 3) The calculated V_ϕ profiles are closer to the measurements when NTV torque is included.

Thus we have demonstrated that the integrated simulation model of TOPICS and FORTEC-3D worked successfully, and NTV torque caused by toroidal field ripples is important to evaluate toroidal flow profile in tokamaks.

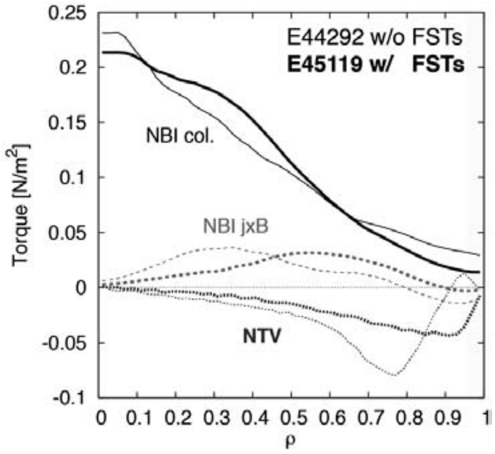

Fig. 1: Radial profiles of collisional and $j \times B$ NBI torque, and the NTV torque before(thin lines) and after(thick lines) inserting the FSTs.

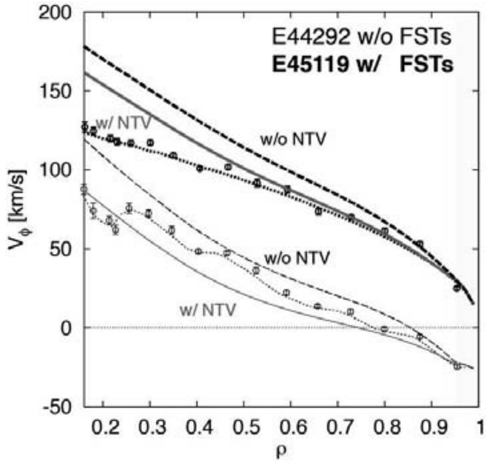

Fig. 2: Toroidal rotation profile in the two cases, with(solid) and without(dashed) including the effect of NTV. Measured profiles are plotted by circles.

1) M. Yoshida *et al.*, Plasma Phys. Control. Fusion vol.48 (2006) 1673.

2) M. Honda *et al.*, Nucl. Fusion vol.53 (2013) 073050.

3) N. Hayashi *et al.*, Phys. Plasmas vol.17 (2010) 056112.

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

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