Topic: TH/C

Study of Neoclassical Toroidal Viscosity in Tokamaks with a δf Particle Code and Resonant Nature of Magnetic Braking

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Non-axisymmetric magnetic perturbations can fundamentally change neoclassical transport in tokamaks by distorting particle orbits on deformed or broken flux surfaces [1]. Understanding transport under non-axisymmetric magnetic perturbations is a critical issue for ITER and future fusion devices where non-axisymmetric perturbations are potentially important control elements to actively stabilize locked modes, edge localized modes, and resistive wall modes. Neoclassical transport with non-axisymmetry, often called Neoclassical Toroidal Viscosity (NTV) transport in tokamaks, is intrinsically non-ambipolar, and highly complex depending on parametric regimes. Progress has been substantially made by various analytical attempts, but a numerical approach is eventually required to achieve a precise and self-consistent description. This paper reports the study of non-ambipolar transport and NTV torque with a new δf particle code - POCA, and the improved understanding of magnetic braking in perturbed tokamaks.

The NTV transport by non-axisymmetric magnetic perturbations provides an additional channel for toroidal momentum transport in tokamaks, and the modification of toroidal rotation by magnetic perturbations in experiments is called magnetic braking. A well-known supposition in magnetic braking is that it is mainly driven by the non-resonant part of magnetic perturbations. However, calculation of non-ambipolar particle flux shows the resonant nature of magnetic braking. To separate the transport by resonant perturbation from non-resonant one, an analytic perturbation with a single resonant mode of $\delta B/B=\varepsilon\cos(m\theta-n\phi)$ was superimposed to the axi-symmetric equilibrium field where q_0= 1.05 and q_a=2.8. Therefore (m=2, n=1) mode resonates at q=2 flux surface. Figure 1 shows the non-ambipolar particle flux around q=2 surface for ε=0.05 by varying poloidal mode and fixing toroidal mode as n=1. It is found that the resonant perturbation significantly enhances the non-ambipolar particle flux. The non-resonant perturbations also enhance the particle flux however their effects are generally weaker than a resonant one. Since the non-ambipolar particle flux is proportional to the NTV torque [1, 2], it is directly correlated to the magnetic braking driven by NTV. The significant enhancement of particle flux by resonant perturbation clearly indicates the strong resonant nature of magnetic breaking. This trend can be stronger by plasma response to magnetic perturbations, which mostly amplifies resonant modes. Another interesting finding is that bootstrap current shows resonant or non-resonant features depending on collisionality. The ion bootstrap current is reduced by the

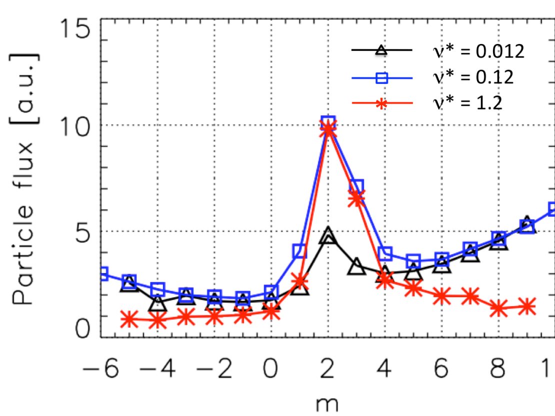

Figure 1. Non-ambipolar particle flux by (m, n=1) perturbations around q=2 surface. The peak particle flux clearly indicates the resonant nature of magnetic braking, which is typically considered as non-resonant.

resonant perturbation in the mid- and high collisionalties but enhanced by the non-resonant ones in the low collisionality as shown in Figure 2. Effects of non-axisymmetric perturbations on bootstrap current are important since it can largely modify the tokamak edge stability. Underlying physics of bootstrap current responding to non-axisymmetric perturbations is under investigation.

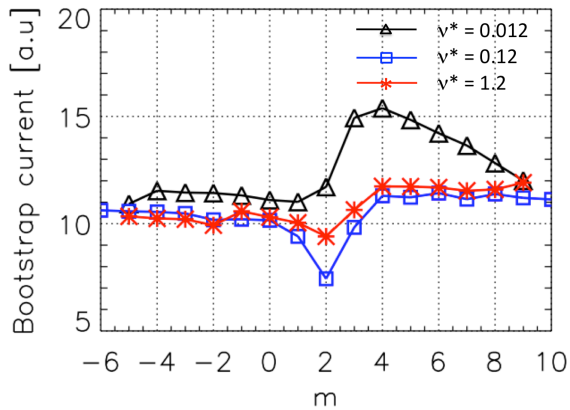

Figure 2. Ion bootstrap current by (m, n=1) perturbations around q=2 surface. Bootstrap current shows resonant or non-resonant features depending on collisionality.

Conservation of toroidal momentum is critical to separate non-axisymmetric effect from axisymmetic one in transport, since it suppresses the particle transport in axisymmetric configuration so the non-ambipolar transport can be distinguished. A new δf particle code, POCA (Particle Orbit Code for Anisotropic pressures), which employs a modified Lorentz collision operator to conserve momentum, has been developed and used for this study. POCA aims to calculate fundamental properties of 3D neoclassical transport and to efficiently provide viable information to a 3D equilibrium solver. POCA solves the Fokker-Planck equation with δf Monte Carlo method [3] to calculate the perturbed distribution function δf. The momentum conserving collision operator of POCA was successfully tested in the axisymmetric case by demonstrating the annihilation of radial particle flux when driven only by like-particle collisions. Another important feature of POCA is that it can easily handle 3D magnetic field information. For instance, POCA can read axisymmetric equilibrium from ESC and EFIT, and non-axisymmetic field from IPEC and analytic model. Then, total magnetic field is determined as a summation of both fields. Such a benefit enables POCA to be practically applicable to experimental analysis as well as basic theory study.

In experimental applications, direct calculation of NTV torque is required to clarify the resonant nature of magnetic braking. The NTV torque can be estimated by calculating the anisotropic pressures and utilizing the magnetic field spectrum method [4]. When expressing the non-axisymmetic field perturbations as a Fourier series $\delta B/B_0=\sum\varepsilon(\psi)\cos(m\theta-n\phi)$, the NTV torque is calculated by following equation

$$\left\langle \hat{\phi}\cdot\nabla\cdot\vec{P}\right\rangle = \left\langle \frac{\delta P}{B}\frac{\partial B}{\partial\phi}\right\rangle = B_0\sum_{m,n} n\varepsilon(\psi)\left\langle\frac{\delta P}{B}\sin(m\theta-n\phi)\right\rangle,$$

where δP is the anisotropic pressures and brackets denote the flux surface average. The NTV torque calculation is being implemented in POCA and its benchmarking with theory is underway. Calculation results of the NTV compared with theory and experiments will be reported, and detailed analyses on magnetic braking in tokamaks such as NSTX will be discussed in the presentation.

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