Topic: EX-S, or EX-C (crosses boundaries)

Physical Characteristics of Neoclassical Toroidal Viscosity in Tokamaks for Rotation Control and the Evaluation of Plasma Response*

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Abstract: Favorable use of low magnitude ($\delta B/B_0 \sim O(10^{-3})$) three-dimensional (3D) magnetic fields in tokamaks includes mitigation of ELMs and Alfvénic modes, and alteration of the plasma rotation profile, ω_ϕ, to strongly affect the stability of NTMs and RWMs. Neoclassical Toroidal Viscosity (NTV) due to the 3D field has been associated with such rotation alteration. NTV research worldwide has raised critical questions for extrapolation to ITER and future devices, including the dependence on collisionality, 3D field spectrum, plasma response, and rotation profile hysteresis. The present work focuses on these critical questions with new analysis of results from NSTX and KSTAR. Experimental angular momentum damping is directly compared to the theoretical NTV torque density profiles, T_{NTV}, created by a range of applied 3D field spectra and plasma parameters in NSTX including configurations with dominant $n = 2$ and $n = 3$ field components. The analysis uses the Shaing formulation of T_{NTV} valid for all collisionality regimes as implemented in the NTVTOK code. Large radial variations of T_{NTV} are often found in ideal MHD models, and appear when the flux surface displacement $\boldsymbol{\xi}$ is derived using an assumption of a fully penetrated $\delta\boldsymbol{B}$. In contrast, experimentally measured T_{NTV} does not show strong torque localization. NSTX experiments yield a computed $|\boldsymbol{\xi}| \sim 0.3$cm, smaller than the ion banana width, and averaging T_{NTV} over the banana width more closely matches the measured *dL/dt* profile. Results from a model-based rotation controller that has been designed and tested using NTV from applied 3D fields as an actuator are shown. A favorable observation for ω_ϕ control, clearly illustrated by long-pulse experiments in KSTAR, is the lack of hysteresis on ω_ϕ when altered by non-resonant NTV. These experiments also show the theoretical scaling of T_{NTV} with $\delta\boldsymbol{B}^2$ and ion temperature $\sim T_i^{2.5}$. The present study takes a unique approach in verifying plasma response models. Due to the strong theoretical dependence of the T_{NTV} profile $\propto \delta\boldsymbol{B}^2$, the experimental T_{NTV} measurements significantly constrain the allowable field from $\boldsymbol{\xi}$ and its plasma-induced amplification. Models presently being tested against experiment include the fully-penetrated $\delta\boldsymbol{B}$ model, and various physics models in the M3D-C^1 resistive MHD code. Initial analysis shows the M3D-C^1 single-fluid model produces a flux surface-averaged $|\delta\boldsymbol{B}|$ magnitude consistent with the experimentally measured T_{NTV}.

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