GYROKINETIC SIMULATIONS OF PRESSURE DRIVEN MAGNETOHYDRODYNAMIC (MHD) INSTABILITIES IN STELLARATOR

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The electromagnetic capability of Gyrokinetic Toroidal Code (GTC) [1] has been upgraded to 3D magnetic geometry. Using the magnetic geometry and plasma profiles constructed from an optimized quasi-axisymmetric (QA) stellarators design [2], GTC simulations find the ideal ballooning modes are unstable, and the kinetic effects of thermal ions are also investigated. Using the magnetic geometry and plasma profiles constructed from W7-X plasmas, a clear toroidicity-induced Alfvén eigenmode (TAE) driven by energetic particles (EP) is identified, with its spectral location matching well with the Alfvén continuum calculated by ALCON and STELLGAP. Moreover, an EP temperature scan shows the mode transitions into an energetic-particle mode (EPM) when additional couplings are considered.

1. PROMOTION OF ELECTROMAGNETIC MODEL IN GTC FOR 3D TOROIDAL GEOMETRY

The stellarator is an attractive fusion reactor concept with steady state operation and reduced risk of disruptions since no plasma current drive is needed. However, the intrinsically 3D magnetic equilibrium could destroy the conservation of canonical angular momentum, allowing particle orbits to drift far away from magnetic flux surfaces, and the breaking of toroidal symmetry could enhance neoclassical transport. Recent designs of optimized stellarators with QA, quasi-symmetry (QS) or quasi-isodynamic (QI) configurations have demonstrated excellent neoclassical confinement. With reduced neoclassical transport, turbulent transport becomes a critical issue for the plasma confinement in stellarators. Electrostatic global gyrokinetic simulations using GTC code have been performed to investigate electrostatic drift wave turbulence and collisionless damping of zonal flows [3]. Besides the electrostatic turbulence, electromagnetic turbulence, such as EP driven Alfvén eigenmodes (AEs), can lead to significant EP losses and degrade plasma heating efficiency. Furthermore, the 3D geometry of stellarators introduces additional couplings between different toroidal harmonics. In the absence of experimental data, the plasma confinement properties in the fusion pilot plant (FPP) burning plasmas remain uncertain. Therefore, electromagnetic gyrokinetic simulations are expected to play a pivotal role in providing critical insights into energetic particle behaviour and in facilitating more comprehensive assessments of stellarator designs. In this work, we upgrade GTC simulation model for electromagnetic simulation with accurate δ current which plays a crucial role in the ideal MHD instability particularly in stellarator.

2. GYROKINETIC SIMULATIONS OF IDEAL BALLOONING MODES

We perform GTC simulations using the equilibrium from the magnetic geometry and plasma profiles constructed from an optimized QA stellarator design. Ideal ballooning modes are found to be unstable, with linear growth rate $\gamma = 1.16 * 10^5/s$ for the $n = 30$ mode.

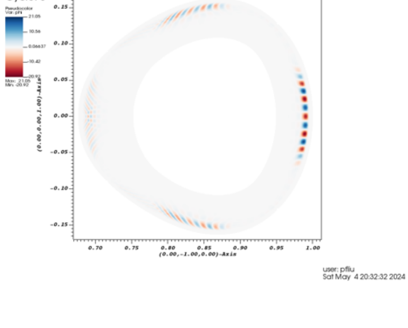

Fig. 1. *Poloidal contour plot of normalized perturbed electrostatic potential $\delta\phi$ from GTC simulation*

3. GYROKINETIC SIMULATION OF ALFVEN EIGENMODES

Using the equilibrium from W7-X device, we perform GTC simulations to investigate the EP driven Alfven eigenmodes. Given the relatively weak neutral beam injection (NBI) in W7-X and its five field periods, we artificially enhance the EP drive to trigger instabilities and simulate one-fifth of the torus to reduce computational cost. In the single-n simulation (only filter out $n = 5$, corresponding to $n = 1$ for one-fifth of the torus), a clear toroidicity-induced Alfvén eigenmode (TAE) is identified, with its spectral location matching well with the Alfvén continuum calculated by ALCON and STELLGAP. However, when multiple toroidal mode numbers ($n = 0,5,10$) are allowed simultaneously, the mode frequency drops to about half of that observed TAE in the single-n simulation. Moreover, an EP temperature scan shows that the instability frequency scales with the square root of the EP temperature $\sqrt{T_f}$, indicating that the mode transitions into an energetic-particle mode (EPM) when additional couplings are considered. Phase space analysis further confirms the resonance between the mode and the EPs.

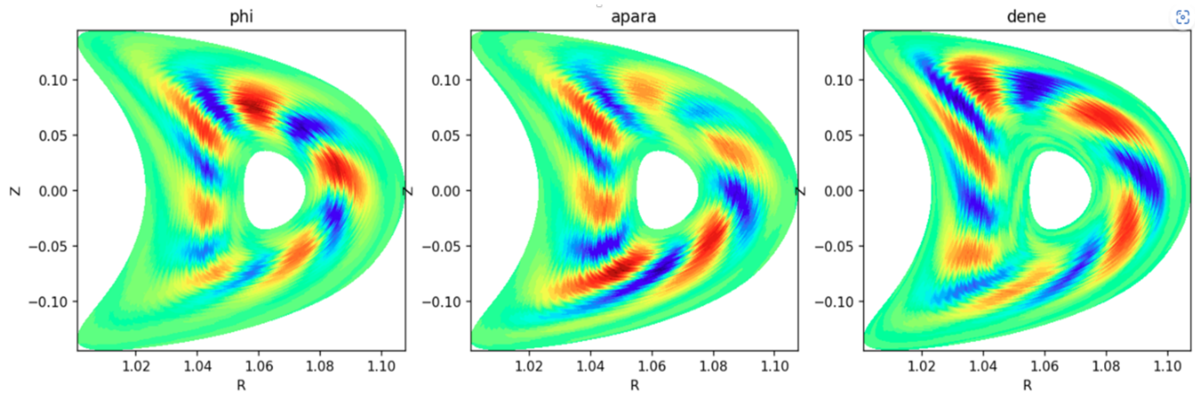

Fig.2. *Poloidal contour plots of normalized perturbed scalar potential* $\delta\phi$*, vector potential* $\delta A_{||}$ *and electron density perturbation* δn_e *from GTC simulation*

REFERENCES

[1] Z. Lin, T. S. Hahm, W. W. Lee, W. M. Tang, and R. B. White, Turbulent Transport Reduction by Zonal Flows: Massively Parallel Simulations, Science **281**, 1835 (1998).

[2] M. Landreman, S. Buller, and M. Drevlak, Optimization of quasi-symmetric stellarators with self-consistent bootstrap current and energetic particle confinement, Phys. Plasmas **29**, 082501 (2022).

[3] H. Y. Wang, I. Holod, Z. Lin, J. Bao, J. Y. Fu, P. F. Liu, J. H. Nicolau, D. Spong, and Y. Xiao, Global gyrokinetic particle simulations of microturbulence in W7-X and LHD stellarators, Phys. Plasmas **27**, 082305 (2020).