9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

An Innovative Stellarator: Variable Symmetry Torus

H. Yamaguchi[1,2], A. Shimizu[1,2], M. Isobe[1,2], K. Ogawa[1,2], M. Osakabe[1,2], H. Takahashi[1,2], S. Satake[1,2], K. Ichiguchi[1,2], T. Murase[1], H. Tanoue[1], S. Nakagawa[1], R. Yanai[1,2], M. Sato[1,2], R. Seki[1,2], S. Toda[1,2], M. Nunami[1,2] and T. Sakai[3]
[1] National Institute for Fusion Science, National Institutes of Natural Sciences
[2] Graduate School of Advanced Sciences, SOKENDAI
[3] Nagoya University
e-mail: yamaguchi.hiroyuki@nifs.ac.jp

Elucidating the effect of magnetic configuration on physics properties of plasma is crucial issue for improving plasma confinement. It has been recognized that three-dimensional magnetic configuration significantly affects plasma confinement performance, such as turbulent transport [1]. Thus, a stellarator with magnetic flexibility is one of the promising option for a next-generation experimental device. We have been designing a new stellarator-type experiment device, the Variable Symmetry Torus (VAST), aimed at realizing both quasi-axisymmetric (QA) and quasi-isodynamic (QI)-like magnetic configurations in a single device. The target device size is similar to that of CHS-qa[2]: R=1.5m and B=1.5T. We found two types of new QA configurations with aspect ratio Ap~4, with different elongations of the plasma cross sections [3]. We chose the QA configuration with better MHD stability property as the primary magnetic configuration for VAST.

To obtain a basic design of the coil system for VAST, the optimization code OPTHECS [4] was used. OPTHECS can optimize the boundary magnetic surface shape as well as the coil shape and current directly targeting the physical properties of generated magnetic configuration and engineering characteristics. The GOSPEL code[5] was used to obtain the initial design of the main modular coils that generate above-mentioned QA configuration. Two types of auxiliary coils, inner modular coils and poloidal field coils, were introduced to enhance magnetic flexibility. Using this initial coil system, coil-shaping-based optimizations were performed using OPTHECS, targeting plasma aspect ratio, magnetic well, reduced neoclassical transport at plasma half radius, and engineering consideration on coil-to-coil distances and coil curvature. After several optimization iterations, and additionally introducing a set of saddle loop coils and fast-ion confinement metric, we obtained a coil system that can generate both QA and QI-like configuration. The QI-like configuration of VAST is not precisely QI but has essential features of QI such as poloidally-closed trapped particle orbits. Coil geometry of VAST is shown in FIG. 1. The number of main modular, inner, and saddle loop coils are 16, 4, and 4, respectively.

MHD equilibrium analysis using the HINT code[7] has shown that finite-beta equilibria up to volume-averaged beta of 4% can be achieved in both QA and QI-like modes. Neoclassical transport level in low-collisionality regime is adjustable from below Wendelstein 7-X (W7-X) to equivalent to LHD shown in [8]. Gyrokinetic simulations using the GKV code[1] have revealed clear differences in the spectrum, intensity, and field-line dependencies of ion-temperature-gradient-driven (ITG) turbulence between QA and QI-like modes. We found that these differences in the turbulence hold even for a QA configuration with symmetry-breaking magnetic ripples, which is neoclassically similar to the QI-like mode. Notably, GKV results reviels that clear and stable zonal flows appear in QI-like mode, which are contributing to the smaller turbulent fluxes in this magnetic configuration. These results imply that studying the effect of magnetic configuration on plasma turbulence is one of the important experimental themes of VAST, which is crutial for turbulence-optimization of a stellarator.

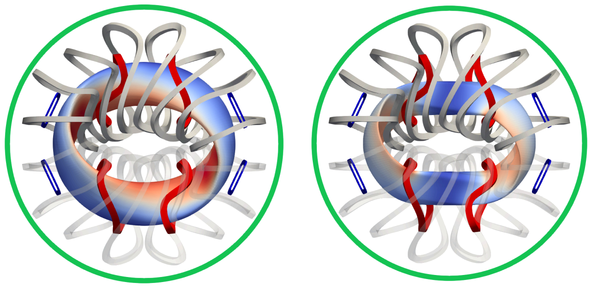

FIG. 1: Coil system with a flux surface of the QA (left) and the QI-like (right) mode of VAST.

References

[1] T.-H. Watanabe and H. Sugama, Nucl. Fusion 46, 24 (2006)
[2] A. Shimizu et al., Fusion Eng. Des. 65, 109 (2003)
[3] H. Yamaguchi et al., 2023 7th Asia-Pacific Conference on Plasma Physics, MFP-57, Port Messe Nagoya, Nov. 12-17
[4] H. Yamaguchi et al., 2023, 29th IAEA Fusion Energy Conference, TH/P2-1
[5] H. Yamaguchi et al., Nucl. Fusion 61 106004 (2021)
[6] Y. Suzuki et al, Nucl. Fusion 46 L19 (2006).
[8] C. D. Beidler et al., Nature 596 221 (2021)
[4] C. D. Beidler et al., Nucl. Fusion 51 076001 (2011)
[10] H. Yamaguchi and S. Murakami, Nucl. Fusion 56 026003 (2016)