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Overview of recent progress in 3D field physics in KSTAR

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In the Korean Superconducting Tokamak Advanced Research (KSTAR), application of external 3D magnetic field (Fig. 1) has been an useful method to actively control various local instabilities such as edge-localized-modes (ELMs) and Alfven eigenmodes (AEs) across the core and the edge-pedestal regions. Recently, several outstanding physical effects of 3D field techniques have been extensively studied in KSTAR [1,2,3], such as long-pulse ELM suppression by resonant magnetic perturbation (RMP), error field (EF) / MHD instability control, 3D field effects on plasma turbulence and transport, and RMP-induced alteration of divertor heat flux and detachment.

One of the promising results from the recent RMP ELM control studies in KSTAR is to demonstrate the highest normalized beta (~2.65) and longest (~45 sec) RMP ELM suppression by exploiting real-time integrated RMP schemes [4]. In these schemes, 3D coils and magnetic fields are properly optimized and adaptively adjusted in real time to reduce the unnecessary confinement degradation and minimize the probability of mode locking, leading to long-pulse sustainment of ELM-suppressed stable (MHD-free) plasmas with maximized core plasma performance and minimized divertor heat load. In particular, an innovative 3D field optimization method, which leverages machine learning and real-time adaptive ELM control, has been implemented in the DIII-D and KSTAR tokamaks to consistently achieve reactor-relevant core confinement and the highest fusion performance without harmful ELM crashes [5].

Sophisticated 3D optimization study also demonstrates that tailoring the EFs can simultaneously stabilize both the core and the edge instabilities of the plasma [6], and reduce the energetic particle (EP) losses [7], thus representing a notable advance for achieving long-pulse ELM suppression for the next-step fusion reactors. Furthermore, reduction of divertor heat flux via radiative power loss has been proven compatible with RMP-driven ELM suppression in a partially detached plasma [8], as required for ITER.

In 3D transport area, density pump-outs by both static and rotating RMPs are experimentally observed and numerically analyzed, showing the importance of island opening at the pedestal foot and top [9] as well as the edge kink-like modes [10] in understanding the origin of 3D density transport. An edge-localized RMP (ERMP) has been successfully applied to sustain a high T_i ($\approx$ 10 keV) advanced confinement regime on the basis of the systematic H-mode avoidance.

Lastly, the future research plan for 3D field physics will be discussed along with particular attention drawn to the recent tungsten divertor upgrade and its implications for the 3D field research in KSTAR.

References

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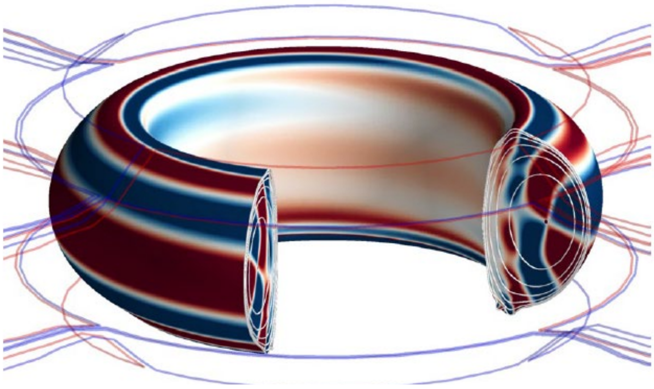

Figure 1. KSTAR three-row (top/middle/bottom) in-vessel control coils and 3D fields. The coil current and 3D field distributions are represented in colors [1].