Phase Space Visualization and Validation of 3D Field Operating Windows for ELM Suppression in KSTAR

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A small degree of 3D relaxation is a key component of tokamaks in the path towards fusion burning plasmas, as it provides the great means to control various instabilities such as edge-localized-modes (ELMs). However, the number of choices available for a 3D magnetic field is virtually unlimited and most of them will only destabilize or degrade plasmas by global symmetry-breaking, presenting a major challenge to the concept of 3D tokamaks. Here, we present a complete visualization of 3D field operating windows for ELM suppression in a tokamak, and its remarkable validation with a complex 3D coil system. The Korean superconducting tokamak advanced research (KSTAR) facility is presently unique by its versatile 3 rows of in-vessel coils, which enabled KSTAR to suppress the type-I ELM crashes using an $n = 1$ resonant magnetic perturbation (RMP) without triggering core MHD instabilities [1] in high-β plasmas and for a duration longer than $\sim 90\tau_E$ [2]. This stable RMP window exists only within a small fraction of the total phase space volume that the KSTAR 3D coils can access, as predicted based on local 3D response metrics and validated by a special group of RMPs [3]. The phase space visualization of RMP windows offered excellent opportunities to navigate all available 3D fields and optimize new RMPs, such as the ones only accessible by dynamic passages, the off-midplane RMPs for the first time in KSTAR, and the potentially favorable RMPs for higher toroidal shaping or wider q_{95} windows. The method and principle adopted in this study is also being used to optimize 3D fields in DIII-D and ITER, and to develop innovative 3D coils feasible for a reactor where long-range ex-vessel RMP solutions are necessary.

References

[1] Y. M. Jeon, J.-K. Park et al., Physics Review Letters **109**, 035004 (2012)
[2] Y. In, J.-K. Park et al., Nuclear Fusion **57**, 116054 (2017)
[3] J.-K. Park, Y. M. Jeon et al., Nature Physics, Under Review (2018)

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