7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

On plasma self-driven current in the context of tokamak steady state operation

Weixing Wang[1], M. G. Yoo[2], E. Startsev[1], S. Ethier[1], J. Chen[1]. S. Kaye[1]
[1]Princeton Plasma Physics Laboratory, [2]General Atomics
e-mail (speaker): wwang@pppl.gov

The steady state operation of future tokamak reactors will largely rely on noninductive, plasma self-driven current (e.g., the neoclassical bootstrap current) for generating the poloidal magnetic field needed for plasma confinement. Magnetic island (MI) perturbations, likely unavoidable in long pulse discharges, may strongly impact both neoclassical and turbulent dynamics (including bootstrap current generation) by altering the topological structure of the confining magnetic field in tokamak devices. MIs usually cause a bootstrap current reduction which could post a significant concern for the economic operation of a tokamak-based fusion reactor. A novel effect revealed by global gyrokinetic simulations results from island-induced three-dimensional ambipolar electric field. A magnetic island is shown to drive electric potential islands with dominant mode numbers the same as that of the magnetic island, whereas centered at both the inner and outer edge of the island. Such non-resonant potential islands may introduce a major change in plasma self-driven current through an efficient nonlinear parallel acceleration of electrons. In large-aspect ratio (large-A) tokamak devices, this new effect can result in a significant global reduction of electron bootstrap current when the MI size is sufficient large, in addition to the local current loss across the island region due to the pressure profile flattening. It is shown that there exists a critical magnetic island width for large-A tokamaks beyond which the electron bootstrap current loss is global and increases rapidly with the island size. As such, this process may introduce a size limit for tolerable magnetic islands in large-A devices in the context of steady state operation. Moreover, this MI-induced non-local modification of the bootstrap current profile may offer a new mechanism, besides the usual magnetic flux pumping process, responsible for the change of q-profile in the core from below 1 to ≥ 1 in the access to sawtooth-free hybrid operation scenario in tokamak experiments which are often associated with the presence of a magnetic island [C. C. Petty et. al, Phys. Rev. Lett. 102, 045005 (2009)]. On the other hand, it remains unexplained in the magnetic flux-pumping process of current profile broadening regarding why it needs a magnetic island to work. Remarkably, in low-A tokamaks (e.g., spherical tokamak), the new effect of MI on bootstrap current is much weaker. The reduction of the axisymmetric current by the magnetic island scales with the square of island width. However, the loss of the current is mainly local in the island region, and the pace of the current loss as the increase of MI size is substantially slower compared to large-A tokamaks. In particular, the bootstrap current reduction by MI in STs is even smaller in the reactor-relevant high-β_p regime where neoclassical tearing mode islands are more likely to develop. It is further noticed that, for the same level of magnetic perturbations $\delta B/B_0$, MHD island width is much smaller in ST geometry than in large-A tokamak. This fact further suggests that MHD islands are more tolerable in STs. The results of this study suggest a significantly favorable feature of ST for non-inductive steady state operation and for developing compact fusion reactors. The connection of this newly revealed effect of MI on the current to some experimental observations will be also discussed.

Work supported by U.S. DOE Contract DE-AC02-09-CH11466, DOE SciDAC Tokamak Disruption Simulation Project and Long Pulse Tokamak Scenario & Control on KSTAR Project.