Optimizing the HSX Stellarator for Trapped-Electron-Mode Turbulence

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Turbulence optimization is an essential consideration for next-generation stellarators, and a key step on the path towards stellarator-type reactors. Similar to tokamaks, present-day stellarator experiments have energy and particle confinement set by electrostatic microinstabilities that drive drift-wave turbulence [2]. For the Helically Symmetric eXperiment (HSX) at the University of Wisconsin-Madison, comparisons between experimental data and gyrokinetic simulations suggest that turbulence driven by density-gradient-driven trapped electron modes (TEMs) limit plasma performance [1]. Here, we present a numerical study to optimize HSX for reduced TEM turbulence. Using the MHD equilibrium code VMEC, we have generated a database of $> 10^6$ magnetic field configurations in HSX. This was done by varying currents in the 48 planar and 48 3D-shaped magnetic field coils. From this database, we show that HSX is capable of generating a large set of helically symmetric magnetic fields, ensuring good neoclassical confinement, while simultaneously elongating the poloidal plasma cross-section. A set of linear and nonlinear gyrokinetic flux-tube simulations have been performed with configurations that exhibit good helical symmetry. These simulations show, relative to the most unstable configuration considered, nearly a ten-fold reduction in the linear growth rates for the lowest binormal wave number, along with a four-fold reduction in the nonlinear heat flux with increasing elongation. The physical mechanism of this stabilization is thought to be related to the sign of the velocity-space average of the bounce-averaged drift frequencies of the trapped electron population with respect to the sign of the drift-wave frequency. In contrast to tokamaks, stellarators contain multiple magnetic wells along a given field line, which exhibit different couplings between the trapped electron drifts and the drift waves. For HSX, it has been found that electrons trapped in the primary magnetic well crossing the outboard mid-plane are stably coupled to the drift waves, while the electrons trapped in the helically connected neighboring wells are unstably coupled. The effect of the coupling is observed to be enhanced with increasing plasma elongation. In addition, the gyrokinetic simulations suggest that the stabilization and destabilization of the primary and secondary trapping wells, respectively, leads to a net stabilization of TEMs over the entire flux tube. Work is currently underway to develop these findings into a TEM stability metric that we will use to search through our coil-current database for configurations with improved transport properties to be explored in experiments at HSX.

References

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