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Effects of turbulence in modifying helicon wave current drive propagation and efficiency

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First-principles helicon wave and scrape-off-layer (SOL) turbulence models show that turbulence can significantly modify the helicon wave behavior and may significantly reduce the helicon current drive efficiency. From previous ray tracing (1) and full-wave modeling (2) efforts without turbulence, helicon waves are expected to be an efficient off-axis current drive actuator for advanced scenarios in current tokamaks and future tokamak reactors. Full-wave models for an example DIII-D discharge without and with SOL density turbulence will be shown. Using realistic and synthetic turbulence inputs, the simulation show that turbulence can scatter and cause interference of the helicon wave, which results in stronger absorption in the SOL and significantly less power and current driven in the core plasma.

These results have been achieved with recently developed wave and turbulence models using experimental inputs from DIII-D for density, temperature, and magnetic field. Helicon wave modeling results using 2-D axisymmetric COMSOL full-wave models that have been benchmarked against hot-plasma ray tracing (GENRAY) and full-wave (AORSA) models (2) for cases without turbulence. The COMSOL model includes a collisional proxy term for SOL damping and core Landau damping. First principle SOL turbulent density simulations for DIII-D have previously been obtained with the HERMES 2-fluid model built from the BOUT++ framework (3). The turbulent density profiles from 140 time slices of these HERMES simulations have been cross-checked with experimental measurements for density fluctuations and used as density input into the COMSOL full-wave model. The turbulence can strongly affect the helicon wave propagation.

Synthetic turbulence density inputs show that fluctuations at high amplitudes and long wavelengths greater than a few cm on average have the largest effect on modifying the helicon wave propagation and absorption. The synthetic turbulence density inputs can either be a single blob, single hole, or a periodic fluctuation to help understand the effect of various turbulent density characteristics on helicon waves. All three synthetic turbulence models show similar qualitative although different quantitative trends. Wave interference and scattering are observed for all models. Low density fluctuation amplitudes or fluctuation with wavelengths far smaller that of the helicon do not strongly impact helicon wave propagation.

High density fluctuation amplitudes and wavelengths can also significantly change the fraction of the helicon power coupled to the core (f_core). Helicon power absorbed in the SOL will reduce the helicon coupled power and current drive efficiency to the core plasma and increase heat loads to plasma facing components. A high value of f_core is therefore desirable. Using a collisional proxy for power absorption in the model, f_core can be computed.

This metric is qualitative and can be used to understand the effect and trends of SOL turbulence of helicon core power. The SOL fractional power losses are correlated with the effects of turbulence on helicon wave propagation. Depending on the synthetic fluctuation characteristics, f_SOL can be significantly higher with SOL turbulence than without SOL turbulence. f_SOL can be calculated not only for synthetic turbulence, but also for HERMES first-principles turbulence density inputs. An ensemble average of the helicon power absorption over the 140 turbulent density profiles from HERMES results in f_core ≃ 73%. Without turbulence, f_core ≃ 97%. These simulations therefore suggest that turbulence can significantly reduce the coupled helicon power and helicon current drive efficiency to the core plasma.

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