Drift-Kinetic theory of Neoclassical Tearing Modes close to threshold

Howard Wilson[1], Jack Connor[2], Alexandra Dudkovskaia[1], Koki Imada[1], Sid Leigh[1]
[1]York Plasma Institute, Department of Physics, University of York, Heslington, York, UK
[2]Culham Centre for Fusion Energy, Culham Science Centre, Abingdon, Oxon, UK

Neoclassical tearing modes (NTM) adjust the magnetic geometry in a tokamak plasma, typically causing a significant reduction in confinement, or even a disruption. They are formed when a "seed" magnetic island causes a local flattening of the pressure gradient, removing the bootstrap current from within the island, which then drives the seed island to larger width. They can be controlled by replacing the missing bootstrap current, and on ITER it is planned that microwaves resonant with the electron cyclotron frequency will provide this. The power required, and the level of localisation of the current drive, depend to some extent on the threshold mechanisms for the NTM. There are two such thresholds, and they are likely related: a threshold in the seed island width, and a threshold in the normalised plasma pressure, β. Our goal is to develop a predictive theory for these thresholds.

The threshold island width is observed experimentally to be comparable to the trapped ion banana width. This complicates the physics because the ions then experience a varying fluctuating electromagnetic field as they progress around their orbits. A theory is presented that retains this physics, based on the drift-kinetic equation. We perform an expansion in the ratio of magnetic island width to system size, which to leading order yields the fact that particle orbits are not affected by the seed island. One can average over these orbits at next order to derive the ion and electron responses. It is demonstrated that the passing particles follow streamlines that lie on island structures in phase-space – these islands are similar to the magnetic island, but shifted radially by a distance of order the poloidal Larmor radius. The shift, which is a consequence of the grad-B, curvature and ExB drifts, is negligible for macroscopic islands, but is important for small islands of width comparable to the particle poloidal Larmor radius. The result is that a density gradient is then partially maintained across the magnetic island, influencing the bootstrap current drive.

Consequences for NTM stability are presented using a new drift-kinetic code and from a reduced analytic model valid in the limit of very low collision frequency. Comparing the results from the two approaches highlights the importance of boundary layers around the island separatrix and at the trapped-passing boundary in velocity space. Results for the particle responses to the magnetic island are presented, together with conclusions for the threshold mechanism.

Acknowledgements: This work was funded by a UKRI EPSRC grant, reference EP/N009363/1