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Equilibrium Pressure-Driven Current in the Presence of a Small Magnetic Island: Singular Behavior and Symmetry Effects

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A small magnetic island has only a small effect on the ambient pressure gradient, so that the pressure is not constant on the flux surfaces in and near the island. The length scale determining which islands may be regarded as "small"in this context is determined by the ratio of perpendicular to parallel transport. We numerically explore the effect of such a small island on the MHD equilibrium current, assuming that the island is sufficiently large that the MHD perpendicular force balance equation retains its validity. This current plays an important role in determining the stability of the island. We show that the effect of a small island on the equilibrium current density can be significant. The pressure-driven current has, in general, a logarithmic (integrable) singularity at the X-line. In an MHD equilibrium that is invariant under combined reflection in the poloidal and toroidal angles (sometimes called "stellarator symmetry"), there is a cancellation, and the singular component of the pressure-driven current vanishes. Conventional models of magnetic islands used in analytical calculations have this symmetry property. Tokamaks with a single null divertor do not. In 3D MHD equilibrium solutions that are constrained to have simply nested flux surfaces, the pressure-driven current has a (nonintegrable) $1/x$ singularity near rational surfaces, where x is the distance from the rational surface. We have numerically investigated the pressure driven current near a small magnetic island in a cylindrical magnetic field with perturbed circular flux surfaces. The perturbation consists of two components, one that modulates the toroidal magnetic field strength without breaking the flux surfaces, and a second that introduces a resonant radial component of the magnetic field at the rational surface but has little effect on the toroidal field. The relative phase between the two perturbations is varied. The Pfirsch-Schlüter current near the X-line is found to be much larger when both perturbations are present and the relative phase between the two breaks the stellarator symmetry than it is when these conditions are not satisfied. The solution near the X-line agrees with the asymptotic limit calculated in a previously published paper. This work was supported by DOE contract DE-AC02-09CH11466 and by the DOE SULI program.

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