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Pressure Driven Currents Near Magnetic Islands in 3D MHD Equilibria: Effects of Pressure Variation Within Flux Surfaces and of Symmetry

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In toroidal MHD equilibria, pressure can generally be regarded as constant on the flux surfaces. The regions near small magnetic islands, and those near the X-lines of larger islands, are exceptions. We show that the variation of the pressure within the flux surfaces in those regions has significant consequences for the pressure driven current. We further show that the consequences are strongly affected by the symmetry of the magnetic field if the field is invariant under combined reflection in the poloidal and toroidal angles. ("stellarator symmetry".) In non-stellarator-symmetric equilibria, the pressure-driven currents have logarithmic singularities at the X-lines. In stellarator-symmetric MHD equilibria, the singular components of the pressure-driven currents vanish. In contrast, in equilibria having p constant on the flux surfaces the singular components of the pressure-driven currents vanish regardless of the symmetry. In 3D MHD equilibria having simply nested flux surfaces, the pressure-driven current goes like 1/x near a rational surface, where x is the distance from the rational surface. To calculate the pressure-driven current near a magnetic island, we work with a closed subset of the MHD equilibrium equations that involves only perpendicular force balance, and is decoupled from parallel force balance. Two approaches are pursued to solve our equations for the pressure driven currents. First, the equilibrium equations are applied to an analytically tractable magnetic field with an island, obtaining explicit expressions for the rotational transform and magnetic coordinates, and for the pressure-driven current and its limiting behavior near the X-line. The second approach utilizes an expansion about the X-line to provide a more general calculation of the pressure-driven current near an X-line and of the rotational transform near a separatrix. The calculations described here are motivated, in part, by tokamak experiments where significant differences are observed between the behavior of stellarator-symmetric and non-stellarator-symmetric configurations with regard to stabilization of edge localized modes (ELMs) by resonant magnetic perturbations (RMPs). Implications for the coupling between neoclassical tearing modes (NTMs), and for magnetic island stability calculations, are also discussed. Supported by DOE contract DE-AC02-09CH11466.

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