Two-Fluid Performance Limits: Stellarator and Tokamak Compared

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Abstract

Stellarator plasmas have generated a number of puzzling observations that resist explanation by the MHD model, in contrast to its success in axisymmetric configurations. Studies with the M3D initial value code show that basic nonlinear two-fluid effects[1], those required beyond MHD to generate the self-consistent diamagnetic drifts of the electrons and ions, relax the major MHD limits on stellarator performance. For the NCSX stellarator, ion FLR and other effects robustly stabilize the most limiting ideal MHD ballooning modes above a certain moderate-to-high mode number and also stabilize resistive MHD ballooning and interchange modes at their most unstable, moderate-to-high mode numbers. Two-fluid models also predict the importance of a "soft" beta limit at high electron β_e, where magnetic islands grow large enough to reduce thermal and plasma confinement and prevent further plasma heating, due to the electron pressure parallel gradient $\nabla_{\|} p_e/(en)$ in Ohm's law. This effect is stronger in stellarators than axisymmetric plasmas, since magnetic islands are driven differently in the two configurations. Neglecting neoclassical stresses, growing tokamak islands rotate, while stellarator islands do not. Existing models of flow effects on island growth (polarization current) do not explain the results. Disagreement arises from the analytical neglect of the two-fluid global steady state conditions and from differences in the actual, compared to the assumed, plasma island evolution. In both configurations, the two-fluid global steady state differs significantly from MHD. The $\nabla_{\|} p_e/(en)$ term and the ion gyroviscous (IGV) stress introduce effects similar to the parallel "momentum damping" of the neoclassical parallel collisional stresses. They drive a global steady state radial electric field E_r, which reverses sign at high p_e/p rather than at low collisionality like the neoclassical field. The ion fluid poloidal velocity $v_{i\theta}$ is significantly damped.

[1] L.E. Sugiyama and W. Park, *Phys. Plasmas* **7** 4644 (2000).