Resonant Axisymmetric Modes in Tokamak Plasmas

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The ideal-MHD theory of axisymmetric modes with toroidal mode number n = 0 in tokamak plasmas is developed. These modes are resonant at the magnetic X-points of the tokamak divertor separatrix. Consequently, current sheets form along the separatrix, which profoundly affect the stability of vertical plasma displacements. In particular, current sheets at the magnetic separatrix lead to stabilization of n = 0 modes, at least on the ideal-MHD time scale, adding an essential ingredient to the mechanism of passive feedback stabilization [1].

The theory discussed here presents analogies with the physics of current sheet formation from the evolution of internal kink modes [2] and the magnetic island coalescence problem [3]. In these works, the ideal-MHD constraint causes magnetic flux to pile up near the X-points, leading to perturbed localized currents and a stabilizing effect in the ideal-MHD limit. For the island coalescence problem, it was found that a chain of magnetic islands becomes ideal-MHD unstable when the island width exceeds a critical threshold. In any case, flux pile-up prevents any further nonlinear evolution for unstable internal kinks and island coalescence unless the ideal-MHD constraint is relaxed, e.g., by resistivity. In our problem, vertical displacements are linearly stable in the ideal-MHD limit when the mode resonance at the equilibrium X-points of the divertor separatrix is appropriately taken into account.

Stable n=0 modes can also be resonant in another way. These modes tend to oscillate at a frequency close to the poloidal Alfvén frequency and are weakly damped by wall resistivity. However, the resonant interaction with fast particles can drive these modes unstable, giving rise to a new type of fast ion instability in tokamak plasmas. This instability may explain recent experimental observations on the Joint European Torus (JET), and it will affect the behavior of fusion alpha particles.

References:

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