Study of stability and rotation of a chain of saturated, freely-rotating magnetic islands in tokamaks

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One of the most important instabilities arising in magnetically confined plasmas is the so-called tearing mode. Magnetic islands result from the nonlinear evolution of tearing modes [1] and represent a serious issue for magnetic confinement devices. In the presence of equilibrium density and temperature gradients, the tearing mode acquires a propagation frequency and the instability is said a drift-tearing mode [2]. Linear theory predicts a propagation frequency of the instability close to the electron diamagnetic frequency, $\omega - \omega_E \approx \omega_{*e}$ (ω_E is the $E \wedge B$ frequency) [3]; however, experimental observations show that, in some conditions, the rotation frequency is closer to the ion diamagnetic frequency, $\omega - \omega_E \approx \omega_{*i}$ [4]. According to a widely accepted interpretation, when the island width becomes larger than the ion-acoustic radius $\rho_s = \sqrt{T_e/(m_i\Omega^2)}$, the ion fluid cannot cross the island separatrix and the island is forced to propagate with the velocity of the ion flow [5]. Most of the theoretical models agree that the magnetic island rotation velocity smootly transitions from the electron direction to the ion direction as the island width grows above the ion-acoustic radius. Plasma dynamics close to a magnetic island is strongly affected by neoclassical effects, that depend on the collisionality regime that characterizes the plasma. Other effects such as finite Larmor radius (FLR) of the ions or non-ideal effects (viscosity, diffusivity), can affect island dynamics. Island rotation velocity also affects stability through the ion polarization current [5], and it can play an important role in the determination of the threshold island width for destabilization of the so-called neoclassical tearing modes (NTMs). In this contribution, we study the non-linear dynamics of a chain of stationary, saturated magnetic islands by solving a four-field system of equations that include non-ideal effects (viscosity, diffusivity), lowest-order FLR effects and neoclassical effects (damping, rotation) [6]. The equations have been deduced as the limit for small ion Larmor radius ($\rho_i k_\perp \ll 1$) of a system of gyrofluid equations; the lowest order FLR corrections to the poloidal flow damping have been calculated by solving a simplified version of the gyrokinetic equation. The FLR corrections thus obtained are consistent with those coming from the small-Larmor-radius expansion of the gyrofluid equations, being both proportional to $\rho_i^2 \nabla_\perp^2 \sim \rho_i^2 k_\perp^2$. This allows to include the FLR effects in a more self-consistent way. The equations are solved by applying a series of perturbative expansions, under some simplifying hypotheses, by following a procedure described in a series of papers by Fitzpatrick ([5] and older ones). These tools are applied to the evaluation of magnetic island stability and rotation, by imposing the torque balance condition, and the results are discussed in the light of current theoretical understanding of the subject and in relation to the experimental observations.

References

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