Resistive wall mode in quasi-stationary collisionless plasmas

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Abstract

According to standard ideal magnetohydrodynamic (MHD) theory, the resistive wall mode (RWM) is a macroscopic instability of tokamak plasmas that limits the maximum achievable beta. The RWM is an external kink driven unstable by the finite electrical resistivity of the metal wall surrounding the plasma. Theories and experiments have shown that the RWM can be stabilized by a combination of fast plasma rotation and dissipation. The fast toroidal rotation is induced by neutral beam injection and its magnitude is a significant fraction of the sound speed. However, reactor-sized plasmas without powerful neutral beams such as ITER's (International Thermonuclear Experimental Reactor) are expected to be stationary or rotate with velocities much slower than the sound speed. Even with active feedback control, the RWM in ITER may not be fully suppressed since the feedback coils are external to the first wall and vacuum vessel. However, standard ideal MHD theories may not correctly predict the stability properties of collisionless plasmas such as ITER's. In this work, we have investigated the stability of the RWM in the ITER-relevant collisionality regime and found that the RWM could be fully suppressed even in the absence of plasma rotation. The stabilization occurs because of the interaction of the mode with the precession drift motion of the trapped thermal ions. Since the RWM magnetic perturbation needs to diffuse through the wall, its mode frequency in the wall frame of reference is negligible with respect to all the other relevant plasma frequencies. It follows that the mode Doppler-shifted frequency in the $\boldsymbol{E} \times \boldsymbol{B}$ drift frame of reference is approximately equal to $\omega_d \simeq -\omega_E = -E_r/(RB_\theta)$ and it can resonate with the trapped particle magnetic drift frequency ω_B. In the absence of flow, the ion equilibrium requires that $\omega_E \simeq -\omega_{*i}$ and the mode-particle interaction is found to be quite strong. The non-resonant particle contribution counteracts the fluid instability drive while the resonant interaction dissipates energy to the trapped particles. The electrostatic terms also play an important role and enhance the kinetic effect. The kinetic effect is included through a sharp boundary model of toroidal plasma keeping the leading order poloidal coupling [1] yielding an algebraic eigenvalue problem. Numerical results [2] from this sharp boundary model show that ITER-like collisionless plasmas could be stable up to the ideal-wall beta limit in the absence of toroidal rotation. This effect is significantly reduced for rotation frequencies much greater than ω_{*i} and it is not expected to play a major role in fast rotating plasmas. This work is supported by the U.S. Department of Energy under Contract No. DE-FG02-93ER54215.

[1] R. Betti, Phys. Plasmas **5**, 3615 (1998).
[2] B. Hu and R. Betti, submitted to Phys. Rev. Lett.