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Nonlinear Simulation of Energetic Particle-driven Alfvén Instability with Source and Sink[1]

JIANYING LANG, Princeton Plasma Physics Laboratory

Kinetic/magnetohydrodynamic hybrid simulations are carried out to investigate the nonlinear dynamics of energetic particle-driven toroidal Alfvén eigenmode (TAE) with collision and source/sink [Phys. Plasmas 17, 042309 (2010)]. We have systematically studied the effect of pitch angle scattering and particle slowing down for different parameter regime and we found that the presence of pitch angle scattering and particle slowing down could shift and broaden the mode resonance and affect the nonlinear saturation of the TAE. For cases well above marginal stability, the mode saturation is approximately steady state with finite collision frequency. The calculated scaling of saturation level with collision frequency agrees well with analytic theory [Phys. Rev. Lett. 68, 3563 (1992)] and NOVA-K. For cases near-marginal stability at low collision rates, the mode saturation exhibits pulsation behavior with frequency chirps up and down. In analogy to the effective collision induced by pitch angle scattering [Phys. Fluids B 2, 2226 (1990)], an analytical calculation indicates that microturbulence-induced diffusivity can affect nonlinear saturation of energetic particle driven modes in the similar way as the pitch angle scattering does. By introducing a simplified diffusion operator to the code, our numerical results have shown that a single TAE mode is to saturate at a steady state with sufficiently high diffusion rate. The simulated saturation level scales with the radial diffusion rate by the same scaling of pitch angle scattering. We derived a criterion to judge the importance of microturbulence-induced radial diffusion effect comparing to the collisional pitch angle scattering effect. According to the criterion, we found that the micro-turbulence induced diffusion could have a stronger effect compared to the Coulomb collision on the TAE saturation in burning plasmas like ITER.

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