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Hybrid kinetic-MHD simulations of interactions between tearing modes and runaway electrons

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Runaway electrons (REs) are of particularly importance to the safe operation of tokamaks. Electrons may be accelerated by the large toroidal electric field arising during a major disruption. Via collisions, an avalanche can set in such that eventually a large fraction of the plasma current is converted into RE current. Without adequate mitigation measures, these energetic electrons may eventually hit the first wall of the device focusing on an extremely localized area, which poses a serious threat to the safe operation of the device. To predict the runaway dynamics during a disruption and develop mitigation strategies, the mutual interaction between REs and the bulk plasma should be carefully considered [1].

In the JOREK code [2], the behavior of REs is described via several ways. The first one relies on a fluid treatment of the REs, self-consistently coupled to the background plasmas [3]. For the runaway current, the contribution from the parallel velocity to the magnetic field and the electric drift velocity are considered. This model does not include the energy/pitch-angle distribution of the particles or the accurate kinetic orbits, limiting the accuracy with respect to transport predictions. Another approach available in JOREK relies on kinetic test particles, which does not couple back to the MHD plasmas, but allows to study transport and wall loads fairly accurately [4].

Present efforts focus on developing a self-consistent coupling of the full-f relativistic PIC model for REs to the background plasmas with a full-orbit model [5] and a guiding center treatment (this work). Additionally, the implementation of the avalanching source is progressing. For the coupling, moments are calculated from the kinetic RE distribution, and then put into the MHD equations to account for the RE contributions to the dynamics. At the same time, REs are described kinetically following the equations of motion in the electromagnetic fields from MHD simulations.

In this work, the accurate representation of the radial force balance of a circular axisymmetric RE beam is verified by comparing to analytical results [1] (shown in Figure 1). Moreover, a comparison to literature [6,7] is done for the linear simulation of 3D tearing modes. Simulations about tearing modes with/without runaway current in a large aspect ratio circular device are carried out and the growth rates are consistent with the theory. Finally, preliminary non-linear results are presented for tearing modes in the presence of runaway electrons of different energies, i.e., for different drift orbit shifts of the REs with respect to the flux surfaces of the MHD background equilibrium.

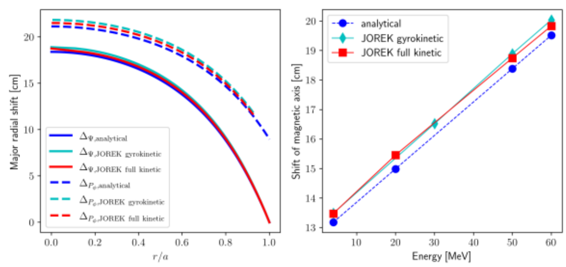

Figure 1. Profiles for the flux surface and drift orbit shifts in the simulation using 50 MeV REs (left) and the shift of the magnetic axis for simulation cases with different RE energies (right).

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