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Nonlinear simulation of kinetic Peeling-Ballooning mode with bootstrap current under the BOUT++ Gyro-Landau-Fluid code*

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The simulation on kinetic peeling-ballooning mode (KPBM) using 3+1 gyro-Landau-fluid (GLF) model under BOUT++ framework is reported. To study the KPBM in the real tokamak equilibrium, we generate a set of realistic equilibria of shifted circular geometry by a global equilibrium solver CORSICA, including the Shafranov shift, elongation, and bootstrap current. We find that the bootstrap current has the stabilizing effects on KPBM, both the growth rate and the unstable region are smaller than the cases without the bootstrap current. The most unstable mode numbers become smaller when β_{PG} increases because the bootstrap current increases with β_{PG} which drives the low-n modes more unstable. Here $\beta_{PG} = 2\mu_0 p_{PG}/B^2$ and p_{PG} is the pressure at the peak pressure gradient. The threshold of the first stable region decreases with the increase of the bootstrap current because the local magnetic shear is smaller shifting the stable boundary into the low α regime. We observe the second stable behavior of KPBM with a much lower β_{PG} threshold than the cases without bootstrap current. However, when the β_{PG} continues increasing, the unstable pure kink mode appears driven by the large bootstrap current. For the whole region of the pedestal, the bootstrap current also plays as a global stabilizing effect on KPBM. In the nonlinear simulation the energy loss with the bootstrap current grows larger than those without the bootstrap current, because the magnetic shear decreases in the region of the large bootstrap current which results in large fluctuation level and turbulent transport. The saturated fluctuation level increases with β_{PG} because the pressure acts as a strong drive of the instabilities and the fraction of the bootstrap current has weak effects on saturated fluctuation level. The turbulence with low β_{PG} is mainly the ballooning dominant turbulence while the turbulence with high β_{PG} is mainly the peeling dominant turbulence. The ion heat transport coefficient first increases and then decreases with β_{PG}. The width prediction of the EPED model in the nonlinear KPBM simulation has also been reproduced.

BOUT++ GLF simulations are performed for ITER's Q=10 high β_P scenario with strong ITB and weak ETB. Here the ITB stands for internal transport barrier and the ETB stands for external transport barrier. The KBMs are stable inside ITB and ETB due to the 2nd region of stability against ballooning modes. However, the KBMs are unstable in the region between ITB and ETB, therefor flattening the profile there which is consistent with the linear local TGLF results by G. M. Staebler (Phys. Plasmas 25, 056113 (2018)).

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