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Quantitative measurements of ion orbit loss from gyrokinetic simulations

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The performance of tokamak plasmas depends strongly on the edge, and the edge plasma performance appears to be strongly affected by the radial electric field E_r and the toroidal rotation. One of many important factors that determine the edge properties is ion orbit loss, which refers to ions leaving the confined region (due to their finite orbit excursion widths across magnetic surfaces) and subsequently hitting the wall. Ion orbit loss has been used to model the formation of strong negative edge E_r during the L–H transition [1, 2, 3], as well as the momentum transport and toroidal rotation at the edge [4]. However, quantitative evaluation of this effect from numerical simulations is yet to be done.

To quantitatively measure ion orbit loss, an orbit-flux formulation has been developed [5, 6]. This formulation allows quantitative measurements of the loss-orbit contribution to the ion radial particle and momentum flux. In particular, it can distinguish between the various physical mechanisms that drive the loss-orbit flux: collisions, turbulent fluctuations, interactions with neutral particles, heating and cooling, and time evolution of the plasma.

We have implemented this formulation as a numerical diagnostic for the massively parallel global gyrokinetic particle-in-cell code XGC [7, 8]. We primarily focus on XGC simulations of an axisymmetric neoclassical plasma. In these simulations, only collisions can drive ion orbit loss. The validity of the diagnostic is demonstrated by studying the collisional relaxation of E_r in the core plasma. After this verification, we numerically measure ion orbit loss in the DIII-D tokamak edge. We have measured a radially outgoing loss-orbit flux due to collisional scattering of ions onto the loss orbits, which is balanced by the radially incoming confined-orbit flux on the time scale of poloidal rotation damping. It is found that the effect of collisional ion orbit loss is more significant for an L-mode plasma compared to an established steady-state H-mode plasma. It is also found that collisional ion orbit loss can create a radially outgoing counter-current momentum flux, thus shifting the edge toroidal rotation in the co-current direction. The potential impact of such a change in toroidal rotation on E_r will be discussed.

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