Implicit full f particle simulations of Alfvén waves and energetic particle physics

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The particle simulation in the whole tokamak plasma volume has attracted significant efforts motivated by the studies of global effects and edge physics [1]. In our previous work, a mixed particle-in-cell (PIC)-particle-in-Fourier (PIF) approach has been implemented using an explicit scheme and unstructured meshes [2]. Implicit PIC with specific discretization scheme in slab geometry has been reported featured with good properties such as energy and momentum conservation and the capability of allowing large time steps [3].

In this work, an implicit scheme for particle-in-cell/Fourier electromagnetic simulations is developed using the $v_\|$ formula and applied to studies of Alfvén waves in one dimension and in tokamak plasmas on structured meshes [4]. An analytical treatment is introduced to achieve efficient convergence of the iterative solution of the implicit field-particle system. Its application to the one-dimensional uniform plasma demonstrates the applicability in a broad range of β/m_e values. The toroidicity induced Alfvén eigenmode (TAE) is simulated using the widely studied case defined by the ITPA Energetic particle (EP) Topical Group. The real frequency and the growth (or damping) rate of the TAE with (or without) EPs agree with previous results reasonably well. The full f electromagnetic particle scheme established in this work provides a possible natural choice for EP transport studies where large profile variation and arbitrary distribution need to be captured in kinetic simulations.

Further ongoing work combines the recent developments from [3, 4] with unstructured meshes extending beyond the plasma separatrix aiming at kinetic ballooning mode simulations at first. The implicit scheme using the $p_\|$ formula is also studied and its properties are analyzed.

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