Progress in simulations with hybrid magnetohydrodynamic gyrokinetic code

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The hybrid magnetohydrodynamic (MHD) gyrokinetic approach \cite{Park1992} is typically used for nonlinear numerical simulations of MHD and Alfvén modes driven by energetic particles (EPs) in Tokamak fusion plasmas. In the hybrid model, the thermal plasma component is described by MHD, while the EP dynamics is accounted for via the divergence of the EP pressure tensor, which is computed by solving the gyrokinetic equation. In order to correctly describe the dynamics of the low frequency domain of kinetic thermal ion (KTI) gap \cite{Chen2007}, where the mode frequency is generally comparable to the thermal ion diamagnetic and/or transition frequencies, kinetic thermal ion effects have to be properly included in the hybrid MHD gyrokinetic model. For this purpose, the hybrid model has been extended, taking into account thermal ion compressibility, diamagnetic effects and finite parallel electric field. The extended version of the hybrid MHD gyrokinetic code (HMGC) \cite{Briguglio1998} (from which the name XHMGC \cite{Wang2011}), with implementation of the extended hybrid model, has been successfully used to study the linear and nonlinear dynamics of beta induced Alfvén eigenmode (BAE) driven by EPs \cite{Wang2012}. Meanwhile, self-consistent test-particle analyses based on numerical diagnostics of resonant particle phase-space have been developed and implemented in XHMGC, with the aim of understanding and elucidating significant roles of finite mode structure effects on the nonlinear dynamics of the mode and EP interactions. The kinetic physics of the extended hybrid MHD gyrokinetic model adopted by XHMGC are crucial for a proper treatment of low-frequency dynamics, such as renormalized plasma inertia response, trapped particle effects, zonal structures and nonlinear saturation as well as transport in toroidal plasma geometries. As simple and clarifying example of this, the Rosenbluth and Hinton scaling \cite{Rosenbluth1998} for the residual level of zonal flow has been obtained with XHMGC. The capability of studying zonal flow dynamics, which is normally investigated with gyrokinetic codes, and more generally of addressing nonlinear dynamics of zonal structures with extended hybrid MHD gyrokinetic codes is, thus, demonstrated for the first time. Further analyses of zonal structure dynamics and their interplay with Alfvénic fluctuations excited by EPs are being pursued.

\begin{thebibliography}{9}
\bibitem{Chen2007} L. Chen and F. Zonca Nucl. Fusion \textbf{47} S727 (2007)
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