Investigation of alpha particle transport induced by Alfvén eigenmodes in CFETR

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China Fusion Engineering Test Reactor (CFETR) is the next-generation fusion facility in the roadmap of Chinese fusion energy development, which aims to bridge the gap between International Thermonuclear Experimental Reactor (ITER) and the magnetic fusion energy demonstration reactor (DEMO). At the moment, one challenge is the confinement of energetic particles (EPs), especially the alpha particles produced by the deuterium-tritium fusion reaction. It has been demonstrated both theoretically and experimentally that Alfvén eigenmodes (AEs) can be destabilized by energetic particles through wave-particle interaction. In present tokamak devices, it is found that AE activity can flatten the energetic particle profile radially, which may degrade fusion performance in a reactor. Therefore, it is crucial to investigate the physical mechanisms of AEs driven by energetic particles and energetic particle transport. In this work, we investigate the AE instability using the hybrid gyrokinetic ion/massless fluid electron model in GEM code [1] with the latest design parameters of CFETR. In addition, a new simplified energetic particle transport model based on the resonance broadened quasi-linear (RBQ) model [2] is developed and applied to investigate the transport of alpha particles in CFETR.

In this work, the parameters and equilibrium profiles according to the latest design of CFETR (steady state scenario) are used. The linear stability of intermediate toroidal mode number $4 \leq n \leq 12$ AEs in CFETR is simulated by GEM, and it is found that the toroidal mode number of the most unstable AE is n=8, which is larger than those in present tokamaks. Furthermore, According to Alfvén continuous spectra of n=7,8,9 modes calculated by NOVA, the radial locations of the modes combined with the mode frequencies relative to Alfvén spectra indicate that these modes are inside the TAE gaps, which indicate that these modes are TAEs. The results indicate that AEs can be driven strongly in CFETR plasmas.

A simplified alpha particle transport model based on the RBQ model is proposed and applied in this work. If the mode frequency is small or the toroidal mode number is large, the diffusion of energetic particle can be assumed just in the radial direction. When the dependence on the velocity space is ignored, the diffusion coefficient can be simplified as $D \propto \gamma A^2$, where D is the radial diffusion coefficient, γ is the mode growth rate, A represents the effective mode structure in the radial direction. Multiple iteration steps are applied to calculate the alpha particle transport in the presence of multiple unstable AEs according to the transport model, and the iteration process is shown as follows. Firstly, the diffusion coefficient is calculated based on the linear growth rates and mode structures of AEs, which are simulated by GEM with the initial alpha particle density profile, and alpha particle density profile is evolved by solving the diffusion equation. At the next iteration step, we re-calculate the linear growth rates and mode structures of AEs with the updated alpha particle density profile from the previous iteration step, and evolve alpha density profile again until reaching a steady state using the diffusion coefficient corresponding to the updated mode structures and growth rates. This iteration process is repeated until the alpha particle density profile is almost the same with that of the previous iteration step.

Simulation results using the reduced transport model show that, due to multiple unstable AEs, the alpha particle density decreases in the core and alpha particles are transported from the core region to the outer region. We find that the minimum value of the safety factor and the central beta value of alpha particle have significant effects on the alpha particle transport, and the AE-induced alpha particle transport level becomes lower with smaller linear growth rates. In addition, it is found that the transport level and radial range of the redistributed alpha particle density profile depend on the radial location.

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