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Application of Particle Orbit Tracking Model in Tokamak Buring Plasmas

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The particle orbit tracking model is a powerful tool for analyzing the dynamics of charged particles in magnetically confined plasmas, particularly in tokamak devices. This model simulates the trajectories of individual particles under the influence of electromagnetic fields, providing detailed insights into particle behavior and plasma confinement. In this study, we present the application of a recently developed code PTC, which utilizes the particle orbit tracking model to simulate a wide range of physical processes in tokamak plasmas [1]. The PTC code is capable of modeling alpha particle behavior [2], neutral beam injection (NBI) heating [3,4,5], current drive, synergistic effects of NBI and ICRF heating, and the physics of runaway electrons [6,7]. By incorporating both the Lorentz force and drift orbit approximations, PTC captures a comprehensive range of particle dynamics, from guiding center motion to fine-scale gyration. The results demonstrate the code's versatility in addressing critical challenges in plasma physics, such as optimizing magnetic configurations, mitigating particle losses, and improving the stability and performance of tokamak reactors. This work highlights the capabilities of PTC in advancing the understanding of complex plasma phenomena and contributing to the development of controlled nuclear fusion.

In fusion plasmas, α particles are crucial for achieving self-sustained burning conditions. Recent studies [8] have shown that in the Chinese Fusion Engineering Test Reactor (CFETR) tokamak, the most unstable TAE modes exhibit significantly higher toroidal mode numbers ($n = 7\sim10$) compared to existing devices ($n = 1\sim4$). We compared the effects of high-n TAE and low-n TAE on the transport of α particles using the PTC code, focusing on CFETR 2019 steady-state scenario. Three phases of TAE evolution are analyzed: linear growth, weak saturation, and strong saturation. During growth phase, resonant α particles are transported radially from resonance positions towards the core and boundary of the plasma. In the nonlinear saturated phase, resonant particles form island structures in the $\Theta - P_\phi$ phase space, as shown in Figure 1, where Θ represents the wave-particle phase, and P_ϕ is the toroidal angular momentum. Notably, island widths are wider for high-n TAE, indicating increased particle radial transport. When TAE saturation amplitudes are large, high-n resonance islands overlap radially, leading to substantially enhanced transport scales for associated α particles, particularly pronounced for $n = 7, 8, 10$ modes. This study reveals the danger of high-n TAE on α particle transport in CFETR-like tokamaks.

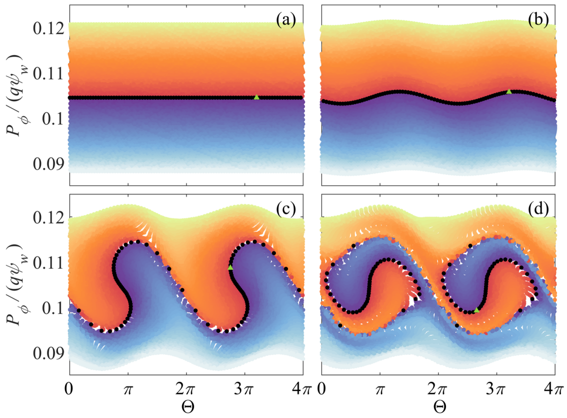

Figure 1. Evolutions of Kinetic Poincaré plots in $\Theta - P_\phi$ phase space for α particles near the resonant relationships $\omega_{AE} = 10\omega_\phi - 33\omega_\theta$. The test particle markers are colored by the initial P_ϕ: orange-yellow color for $P_\phi > P_{\phi\, res}$, purple-blue color for $P_\phi < P_{\phi\, res}$, black color for $P_\phi = P_{\phi\, res}$.

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