HYBRID SIMULATION OF LINEAR AND NONLINEAR DYNAMICS OF ENERGETIC PARTICLE DRIVEN MAGNETOHYDRODYNAMIC INSTABILITIES IN HELIOTRON J

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Clarification of interaction between energetic particles (EPs) and magnetohydrodynamics (MHD) waves is necessary to realize self-sustainable fusion plasma. In stellarator and heliotron configurations, toroidally asymmetric magnetic components (e.g. helicity and bumpiness) generate additional SAW-SAW[1] couplings and EP-SAW resonances[2]. In this study, the linear and nonlinear dynamics of EP-driven MHD instabilities in Heliotron J[3], a low magnetic shear helical-axis heliotron, are investigated with MEGA[4], a full MHD-EP hybrid simulation code. The n/m=1/2 energetic-particle-mode (EPM) and the n/m=2/4 global Alfvén eigenmode (GAE)[3] which were observed in a Heliotron J experiment are successfully reproduced with the simulation. It is found that the free boundary condition is necessary to reproduce the experimental observation[5-6]. Without the free boundary condition, the spatial profile of these modes is limited to the core region, which results in a significant reduction in the EP driving rate when the spatial gradient of EP pressure (∇P_h) is finite near the edge region. Due to the low magnetic shear, the n/m=1/2 EPM and the n/m=2/4 GAE have radially broad spatial profiles. The mode couplings due to the helicity and the bumpy components are weak for the spatial profile. A kinetic analysis clarifies that these modes are driven mainly by the high-velocity co-passing EPs through the toroidicity-induced resonances. The effects of toroidally asymmetric resonances are negligible because they are localized in the low-velocity region. During the nonlinear phase, the asymmetric downward frequency chirping of the n/m=1/2 EPM occurs. The upward branch is dissipated because the resonant velocity of the hole formed at the high-velocity toroidicity-induced resonance exceeds the NBI injection velocity. The results of this work will contribute to the three-dimensional optimization of fusion-grade stellarator and heliotron devices and the simulation of EP-driven MHD modes in other low magnetic shear stellarators and heliotrons.

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