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Simulations of two types of energetic particle driven geodesic acoustic modes and the energy channeling in the Large Helical Device plasmas

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Energetic particle driven geodesic acoustic modes (EGAMs) in the Large Helical Device (LHD) plasmas are investigated using MEGA code. MEGA is a hybrid simulation code for energetic particles (EPs) interacting with a magnetohydrodynamic (MHD) fluid. In the present work, both the conventional and extended models of MEGA are employed. In the conventional model, only the EPs are described by the kinetic equations, while in the extended model not only the EPs but also the thermal ions are described by them. The simulations are conducted based on realistic parameters. The energy of neutral beam injection (NBI) is 170 keV. A Gaussian-type pitch angle distribution is assumed to model the NBI energetic ions. Using MEGA with a conventional model, it is found that the transition between low frequency EGAM and high frequency EGAM is decided by the slope of EP velocity distribution. Also, the phase difference between the bulk pressure perturbation $\delta\mathrm{P}_{\mathrm{bulk}}$ and EP pressure perturbation $\delta\mathrm{P}_{\mathrm{EP}}$ are analyzed. For the low frequency EGAMs, $\delta\mathrm{P}_{\mathrm{bulk}}$ and $\delta\mathrm{P}_{\mathrm{EP}}$ are in anti-phase. They cancel each other out, which reduces the restoring force of the oscillation leading to the low frequency. While for the high frequency EGAMs, $\delta\mathrm{P}_{\mathrm{bulk}}$ and $\delta\mathrm{P}_{\mathrm{EP}}$ are in the same phase. They enhance each other, and thus the frequencies are higher. Using MEGA with an extended model, the low frequency EGAMs are reproduced. The mode structure, mode number, and mode frequency are not only consistent with the results of conventional MEGA model but also consistent with theory and experiment. Also, the energy transfer of various species is analyzed and the bulk ion heating during the EGAM activity is observed. The ions obtain energy when the EPs lose energy, and this indicates that an energy channel is established by EGAM. The EGAM channeling is reproduced by simulation for the first time. From t = 0 to t = 0.36 ms, the energy transferred from EP is 63 J. About half of this energy (51%) is transferred to bulk ions (34%) and electrons (17%), while another half is dissipated. The heating power of bulk ions around t = 0.1 ms is $3.4\ \mathrm{kW/m^3}$ which is close to the value $4\ \mathrm{kW/m^3}$ evaluated from the experiments.

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