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Simulation of energetic particle driven geodesic acoustic mode channeling in the Large Helical Device

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Geodesic acoustic mode (GAM) is an oscillatory zonal flow coupled with density and pressure perturbations in toroidal plasmas. In the LHD experiment, anomalous bulk ion heating during the energetic particle driven GAM (EGAM) activity suggests an energy channel created by EGAM[1]. The phenomenon of EGAM channeling has not yet been deeply investigated by simulation, although it has direct significance for plasma heating efficiency. Then, the motivation of the present proceeding is to clarify the mechanism of EGAM channeling.

A hybrid simulation code for energetic particles (EPs) interacting with a magnetohydrodynamic (MHD) fluid, MEGA[2], is used for the simulation of EGAM. Both the bulk ions and EPs are described kinetically. A realistic 3-dimensional equilibrium generated by HINT code is used for the simulation.

A mode is reproduced by MEGA code. The magnetic perturbation is much weaker than the poloidal velocity, thus this is an electrostatic mode. The dominant poloidal mode number is m = 0 for poloidal velocity, m = 1 for pressure perturbation, and m = 2 for magnetic perturbation. The simulated mode numbers are the same as GAM mode numbers. Also, the mode width is large, and it is a global mode. Because of the above properties, the simulated mode is identified as an EGAM.

The mode frequency in linear stage is 50 kHz, and then, frequency chirps up in the nonlinear phase with time evolution. At t = 0.5 ms, the frequency has already exceeded 60 kHz. The linear stage is from t = 0 to about t = 0.1 ms. At t = 0.1 ms, the mode amplitude reaches the maximum value, and then, steps into the nonlinear phase. Fig. 1 shows the energy transfer of various species. The product of the perpendicular current of each species and the electric field is integrated in space and time. The perpendicular current consists of ∇B and curvature drift current, and magnetization current. 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 kW/m^3.

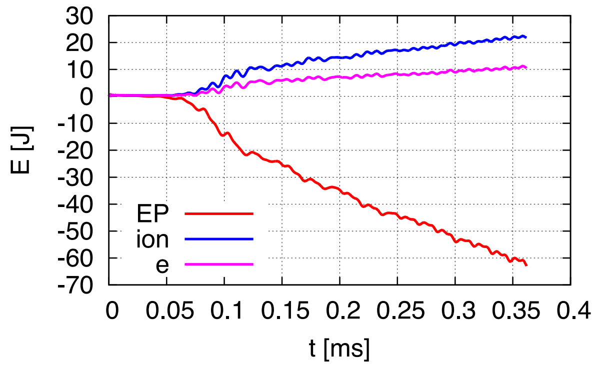

Fig. 1 Energy transfer of various species.

In order to investigate the resonant particles, the δf distribution of bulk ions at different times are analyzed in the particle transit frequency f_{tr} space. A clump around f_{tr} = 25 kHz is formed. The transit frequencies of bulk ions in this clump increases with time evolution, and this transit frequency is kept at half the EGAM frequency. The resonance condition between EGAM and bulk ions is given by

$$f_{EGAM} = l \cdot f_{tr,bulk}$$

where l = 2. The energy transfer rate of bulk ions in f_{tr} phase space is also analyzed. There is a peak around f_{tr} = 25 kHz, and the frequency of this peak gradually increases. This increasing indicates that the bulk ions with half mode frequency are kept resonant with the mode and absorb energy from EGAM. This is the first time to quantitatively reveal the resonance condition between EGAM and bulk ions during the establishment of EGAM channeling.

Reference

[1] M. Osakabe *et al*, IAEA FEC, 2014.
[2] Y. Todo *et al*, International Toki Conf., 2017.