§10. Interaction between Energetic Particles and Alfvén Eigenmodes in Reversed Shear Plasmas

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Alfvén eigenmodes are important issues in the current fusion science and technology. An important question for fusion burning plasmas is whether the energetic particle transport changes or not when the transition between reversed shear Alfvén eigenmodes (RSAE modes) and toroidal Alfvén eigenmodes (TAE modes) takes place. In order to answer this question, we have investigated the interaction of energetic particles with RSAE modes or TAE modes using the MEGA code[1], a hybrid simulation code for magnetohydrodynamics (MHD) and energetic particles. We focus on the difference in energetic particle transport between RSAE modes and TAE modes. When the energetic particle distribution is isotropic in velocity space, we have found that the energetic particles both co- and counter-going are transported by the TAE modes, whereas only the co-going particles are transported by the RSAE modes. The growth rate takes the minimum value just before the transition from RSAE mode to TAE mode. The reason for these results are examined by complementary simulations using purely co- or counter-going energetic particles.

We focus on $n = 4$ Alfvén eigenmodes, which are exact solutions of the equations of a quarter of the tokamak domain with the toroidal angle taken from $0 \le \phi \le \frac{\pi}{2}$. Then, the simulation region is $R_c - a \le R_c \le R_c + a, 0 \le \phi \le \frac{\pi}{2}$ and $-a \le z \le a$, where R_c is the major radius. The outermost magnetic surface is circular with aspect ratio $R_c/a = 3.0$. The number of marker particles is 5.24×10^5, but a larger particle number is also used to investigate the numerical convergence. The number of grid points is $100\times16\times100$ for the cylindrical coordinates (R, ϕ, z). The viscosity and diffusivity are set to be $\nu = \nu_n = 10^{-6} v_A R_c$ and the resistivity $\eta = 10^{-6}\mu_0 v_A R_c$ in the simulation, where v_A is the Alfvén speed. Different energetic particle slowing-down distribution functions, i) slowing-down distribution which is isotropic in velocity space, ii) slowing-down distribution with only co-passing particles, and iii) slowing-down distribution with only counter-passing particles, are applied to study the differences between RSAE modes and TAE modes.

When the energetic particle distribution is isotropic in velocity space, the transition from low-frequency RSAE mode to TAE mode was demonstrated as the minimum safety-factor value decreases from 1.975 to 1.825. The frequency rises up from a level above the geodesic acoustic mode frequency to the TAE frequency. This qualitatively reproduces the frequency up-shift observed in the tokamak experiments. In addition, it was found that the energetic particles both co- and counter-going to the plasma current are transported by the TAE mode, whereas only the co-going particles are transported by the low-frequency RSAE mode, as shown in Fig. 1.

In order to acquire the better understanding of the role of the co- and counter-going particles, the additional runs were performed with only co- or only counter-passing particles. It was found that when only the co-passing particles are retained, the low-frequency RSAE modes are destabilized. On the other hand, the high-frequency RSAE modes are destabilized when only the counter-passing particles are retained. In the purely co-passing and the purely counter-passing particle cases, no TAE mode was destabilized for the low q_{min} values. This is different from the isotropic velocity distribution case where the TAE modes are destabilized for the low q_{min} values, although the energetic particle beta values for the co-passing and the counter-passing particle cases are chosen so that the growth rate for $q_{min} = 1.95$ is close to that for the isotropic velocity distribution case. This difference arises from the fact that for the isotropic velocity distribution, both the co-going and the counter-going particles interact with and destabilize the TAE modes while only the co-going particles interact with the low-frequency RSAE modes.

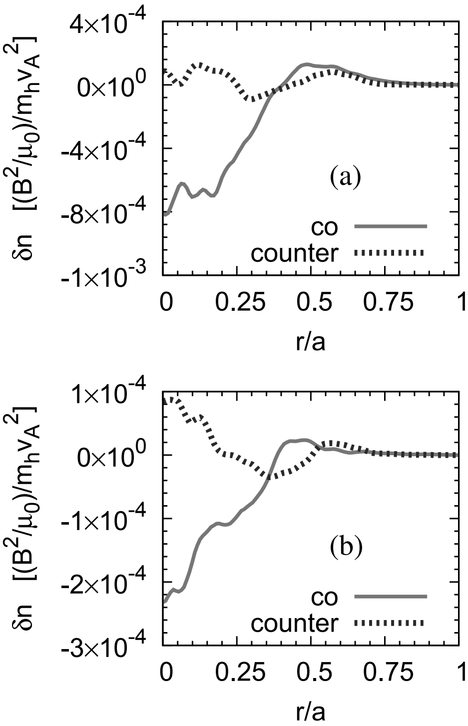

Fig. 1: Comparison of energetic particle density profile perturbations between (a) RSAE mode for $q_{min} = 1.95$ and (b) TAE mode for $q_{min} = 1.875$. Co-going particles to the plasma current are transported by the RSAE mode; whereas both the co- and counter-going particles are transported by the TAE mode.

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