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Numerical study of kinetic low frequency electromagnetic continuous spectrum with the DAEPS code

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The low frequency fluctuation spectrum in tokamaks, including beta-induced Alfvén eigenmode (BAE), beta-induced Alfvén acoustic eigenmode (BAAE) and low frequency Alfvén wave (LFAW), as a result of the curvature-pressure coupling of Alfvénic branch and acoustic branch, have attracted a lot of interest, since they can be excited by both thermal and fast particles in various parameter regimes [1], which implies that a kinetic approach is needed for accurate treatment. Additionally, the kinetic approach is also necessary for the spectrum with even lower frequencies, comparable or lower than thermal ion bounce frequencies (ω_{Bi}), where the trapped thermal ion dynamics becomes important [2-4].

The drift Alfvén energetic particle stability (DAEPS) code is used to perform the numerical analysis of low frequency kinetic continuous spectrum in toroidal fusion plasmas. The DAEPS code is an eigenvalue code using the finite element method (FEM) to study low frequency Alfvénic fluctuations [5]. It has shown to be capable of accurately calculating the frequency, growth rate, as well as asymptotic behavior of the mode structure in the inertial layer, which gives the possibility of properly handling the continuous spectrum. The theoretical and numerical model, including thermal ion compressibility and diamagnetic effects, is then constructed to describe well circulating and deeply trapped particles [3-4]. With the Fourier spectral FEM, the DAEPS code can perform numerical studies of low frequency kinetic continuous spectra. Furthermore, it can calculate the inertial layer contribution, due to the close connection with the general fishbone-like dispersion relation (GFLDR) theoretical framework in the local limit, $i\Lambda = \delta\overline{W}_f + \delta\overline{W}_k$ [6-8]. The diamagnetic effect neglecting temperature gradient is numerically analyzed for the kinetic continuous spectra and corresponding gap modes; i.e., the kinetic ballooning mode (KBM), BAAE and BAE. The numerical result suggests that the frequency of the accumulation point of LFAW branch strongly depends on the ion diamagnetic frequency (ω_{*pi}), which can approach and even exceed the BAE branch as ω_{*pi} increases. It is also observed that, when the frequencies of LFAW and BAE branches are close, the frequencies of the corresponding gap modes, i.e., KBM and BAE, are close as well, while their growth rates undergo a drastic change for increasing ω_{*pi}. This phenomenon can be explained with the physics picture of reactive "beam-plasma" instability in terms of coupling between BAE and KBM, which are positive and negative energy waves, respectively. Analytical study suggests that, when the frequencies of KBM and BAE are very close, the growth/damping rate has $\mathrm{Im}\delta\omega \approx \pm i\omega_A \left|\delta\overline{W}_f\right|/\sqrt{2}$. These results illuminate recent experimental findings in DIII-D [9].

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