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Theoretical research on neoclassical effects on low frequency drift Alfvén waves in Tokamak plasmas

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Alfvén waves and energetic particles, resulted from fusion reaction and auxiliary heating, are crucial to the performance of Tokamak devices. The theoretical research on low frequency drift Alfvén waves (DAW) is based on the general fishbone-like dispersion relation (GFLDR) and gyrokinetic theory [1]. Besides recovering diverse limits of the kinetic magnetohydrodynamic (MHD) energy principle, the GFLDR approach is also applicable to electromagnetic fluctuations, which exhibit a wide spectrum of spatial and temporal scales consistent with gyrokinetic descriptions of both the core and supra-thermal plasma components. Formally, the GFLDR can be written as

$$i\Lambda = \delta W_f + \delta W_k, \tag{1}$$

where Λ is the generalized inertia, and δW_f and δW_k are, respectively, fluid and kinetic potential energy of electromagnetic fluctuations.

In the original theoretical works [2] on DAW, ions considered in the kinetic analysis are assumed to be well circulating. Later on, the kinetic analysis was extended by including the deeply trapped ions and electrons [3]. Moreover, the researches mentioned above are all based on the $s-\alpha$ model in Tokamak plasmas with circular configuration. However, the effects of general magnetic geometry and full circulating/trapped particles are not included in previous researches. Especially, the particles near circulating/trapped separatrix are not included in the previous theoretical models. In order to obtain a better understanding of experimental observations and provide a more precise kinetic model for theoretical researches, we need to include the general magnetic geometry and full orbit effects without assuming well-circulating or deeply-trapped ions and small ion orbit width.

In this work, we present a kinetic model with general magnetic geometry and arbitrary ion orbit width. With this general model, one can solve the problem of DAW in the inertial layer numerically as long as the guiding center orbit information is provided. By taking small ion orbit width limit and applying the $s-\alpha$ model, a simplified mode with full circulating/trapped ions effects is obtained. The generalized inertia with the modification of neoclassical effects can also be calculated with appropriate circular geometry data. Furthermore, if we assume ions are well circulating or deeply trapped, the results go back to those of the previous researches [3,4]. Finally, an interpolated formula of the BAE frequency of the accumulation point is given as

$$\omega_{BAE} = q\omega_{ti}\sqrt{\tau + \frac{7}{4} - 1.7\tau\sqrt{\epsilon} - 0.2\sqrt{\epsilon}}, \tag{2}$$

where q is the safety factor, ω_{ti} is the thermal transition frequency, τ is the ratio of electron temperature over ion temperature and ϵ is the inverse aspect ratio. The comparison with the numerical result is presented in Figure 1.

References
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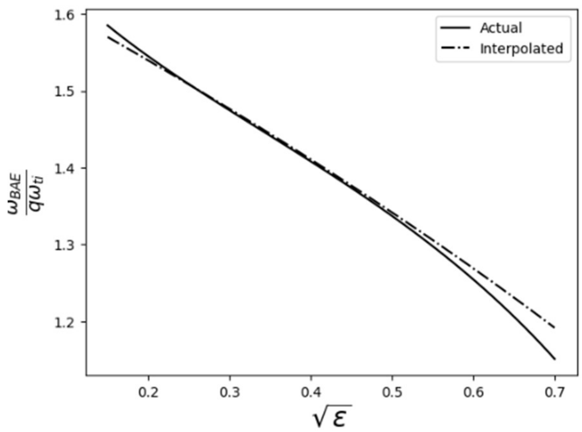

Figure 1. Neoclassical correction on the accumulation point of BAE for τ≈1.