Toroidal modeling of energetic passing particle drift kinetic effects on tearing mode stability

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Neutral beam injection (NBI) is an important auxiliary heating method that has been successfully utilized to achieve the H-mode regime, and is widely implemented in many present-day tokamaks as well as foreseen for future devices such as ITER. Energetic particles (EPs) induced by NBI, on one hand, heat the background plasma via collisions and are hence important for achieving advanced operation scenarios with high plasma pressure; on the other hand, can significantly modify MHD stabilities via the wave-particle interactions. The roles played by EPs in various macroscopic MHD instabilities have been extensively investigated for decades.

Compared to the aforementioned instabilities, effects of EPs on the resistive instabilities, in particular the tearing mode (TM), have been less exploited. In fact, EPs do affect the tearing mode by modifying the perturbed parallel current. We note that most of the theoretical studies on TM-EP interaction, including that from Ref. [1], assume tokamak plasmas with vanishing equilibrium pressure. This simplified assumption, however, eliminates certain fundamental physics associated with the resistive layer, such as the favorable average curvature effect [2] due to finite pressure gradient across the mode rational surface, and anisotropy of the thermal transport within the resistive layer [3]. It has been found that the anisotropic thermal transport, combined with EPs drift kinetic resonances, is shown to stabilize the resistive plasma resistive wall mode [4]. It is therefore desirable to understand the EPs role in the TM stability, while including the effect of finite plasma pressure and anisotropic thermal transport. Such a study has not been performed before, and will be the focus of the present work.

In this work, we assume a tokamak plasma equilibrium with finite pressure (and pressure gradient). We then carry out a systematic study of the drift kinetic effects of NBI induced co- and counter-passing EPs on the TM stability via toroidal modeling utilizing MARS-K [5]. Anisotropic thermal transport physics will also be considered.

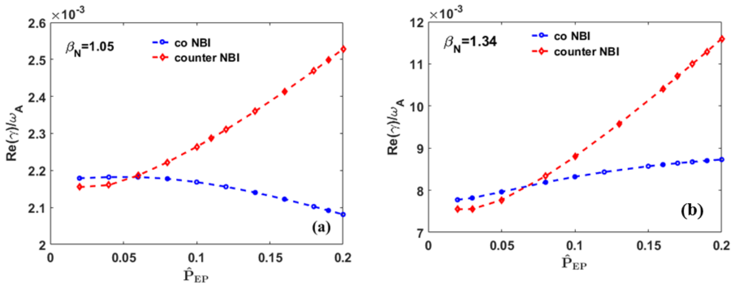

Fig. 1. The computed growth rate of the n=1 (with the dominant poloidal harmonic of m=2) tearing mode, while varying the EPs pressure faction $\hat{P}_{EP}$. Results assuming the co- (in blue) and counter- (in red) tangential NBI models are compared.

In the low beta limit, our results qualitatively agree with that reported in Ref. [1], i.e. that counter-passing EPs destabilize the TM while co-passing EPs stabilize the mode (Fig. 1(a)). However, as the plasma pressure increases and exceeds a critical value ($\beta_N^{cric} = 1.2$ in this work), we find that co-passing EPs begin to play a destabilizing role, as shown in Fig. 1 (b). The latter is understood as a result of two competing effects: the stabilizing effect by the non-adiabatic drift kinetic contribution of co-passing EPs and the destabilizing effect by the adiabatic contribution. The latter is substantial enhanced by higher plasma beta, leading to a net destabilization effect by co-passing EPs.

The drift kinetic effect of co- and counter-passing EPs also yield different modifications to the radial structure of the TM. Counter-passing EPs significantly alter the poloidal spectrum of the radial displacement by enhancing the sideband harmonics.

References

[1] Cai H. S.et al. 2012 *Phys. Plasmas* **19** 072506

[2] Glasser A.H. et al 1975 *Phys. Fluids* **18** 875

[3] Bai X.et al 2017 *Phys. Plasmas* **24** 102505

[4] Bai X.et al 2020 *Phys. Plasmas* **27** 072502

[5] Liu Y.Q. *et al* 2008 *Phys. Plasmas* **15** 112503