8th Asia-Pacific Conference on Plasma Physics, 3-8 Nov, 2024 at Malacca

Kinetic effects of thermal ions on internal kink modes in tokamak plasmas

Jiangyue Han[1], Yasushi Todo[1,2], Hao Wang[2], Masahiko Sato[2]
[1] Graduate School of Frontier Sciences, The University of Tokyo,
[2] National Institute for Fusion Science
e-mail (speaker): han.jiangyue@nifs.ac.jp

Relatively few studies have investigated the effects of thermal ions on internal kink modes in tokamak plasmas, primarily due to the low energy associated with thermal ions. In this work, we performed kinetic-MHD hybrid simulations with kinetic thermal ions (KTI-MHD) to investigate the kinetic effects of thermal ions on internal kink modes. The kinetic-MHD hybrid simulation model has been implemented in the MEGA code [1]. In this model, the behavior of bulk ions is simulated using kinetic PIC methods, while the electrons are governed by fluid equations.

We use the whole tokamak plasma domain with the toroidal angle range $0 \leqslant \phi < 2\pi$. The simulation cross section is $R_0 - a \leqslant R \leqslant R_0 + a$, and $-1.6a \leqslant Z \leqslant 1.6a$, where $R_0 = 1.65$ m and $a = 0.6$ m are the major radius and the minor radius, respectively. The number of grid points is 256× 32× 256 for cylindrical coordinates (R, ϕ, Z). For the KTI-MHD simulations, we set 64 particles per cell.

The equilibrium was generated by the Grad-Shafranov equation, characterized by a relatively high bulk plasma beta ($\beta = 2\%$) and large safety factor near the plasma edge ($q_a = 10$). The plasma pressure distribution and safety factor profile, based on DIII-D discharge #141216[2], are illustrated in Fig. 1.

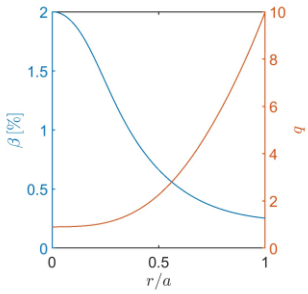

Fig1. Safety factor profile and plasma beta profile.

With safety factor on the axis q_0<1, the internal kink mode with m/n=1/1 is the most unstable mode, and the velocity perturbation profiles in the linear growth phase of the kinetic-MHD hybrid simulation with kinetic thermal ions are similar to those of MHD simulation, as shown in Fig. 2.

We also scanned the parameter `minor_r`, which represents the minor radius of the plasma normalized by the Larmor radius of an ion traveling at the Alfvén speed on the magnetic axis. We confirmed that the linear growth rate γ of the MHD model is independent of `minor_r`. However, γ of the KTI-MHD simulation increases rapidly as `minor_r` decreases and may even exceed the growth rates observed in the MHD simulation.

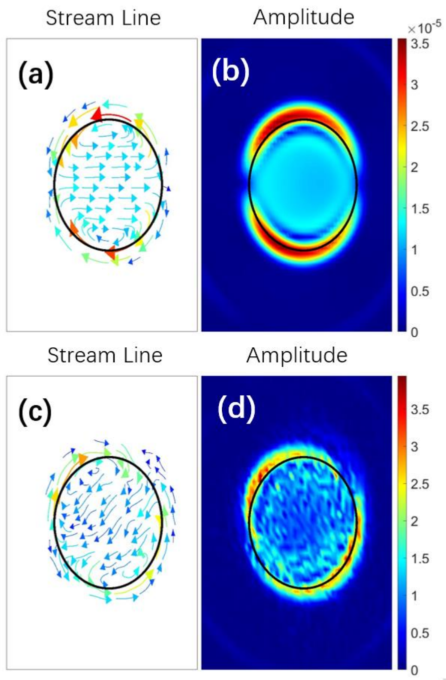

Fig2. Two-dimensional profile of velocity perturbation in (a)(b) MHD simulations and (c)(d) kinetic-MHD simulations. The black solid curve is rational magnetic surface of $q = 1$.

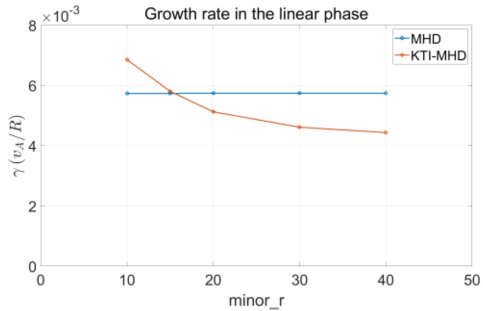

Fig3. Growth rate vs `minor_r`.

The difference in growth rate primarily arises from two terms in the momentum equation: (1) the ion drift velocity correction in the convection term, and (2) the coupling current in the current drive term. We aim to provide an intuitive physical explanation for the dependence shown in Fig. 3.

References
[1] Y. Todo et al., Plasma Physics and Controlled Fusion, 2021, 63(7): 075018.
[2] G. Brochard et al., Nuclear Fusion, 2022, 62(3): 036021.