Name (ID): Xin ZHONG (47206137)
The University of Tokyo
Department of Complexity Science and Engineering, Graduate School of Frontier Sciences
Abstract of Master’s Thesis, 2022 September
Title: Simulation Study of Continuum Damping for Alfvén Eigenmodes in Tokamak Plasmas
Keywords: magnetohydrodynamics (MHD), Alfvén eigenmodes, hybrid simulation, continuum damping
Advisor: Professor Yasushi Todo

Abstract

Alfvén wave is a low frequency electromagnetic wave which propagates in the plasma in the direction of the magnetic field. It is a transverse wave with the direction of vibration perpendicular to the direction of propagation. The frequency of Alfvén wave varies continuously with spatial location, forming a continuous frequency spectrum which is called Alfvén continuum. It is theoretically predicted that the continuous spectrum produces a phase mixing effect that strongly damps the Alfvén waves. This damping mechanism of Alfvén wave is called continuum damping. In tokamak plasmas, the coupling of poloidal harmonics *m* and *m+1* creates a frequency gap in the Alfvén continua, where toroidal Alfvén eigenmode (TAE) can exist without continuum damping. TAEs can be driven unstable by the resonant interaction with energetic particles whose orbit frequency is close to that of the TAE. TAEs can lead to the loss of energetic particles and deteriorate the plasma confinement. It is important to control the TAE instability.[1]

The phase mixing theory indicates that the difference in oscillation phase is larger for larger gradient of the continuous spectrum.[2] The viscous and resistive dissipations are enhanced due to phase mixing. In this thesis, we have investigated numerically the continuum damping mechanism with kinetic magnetohydrodynamic hybrid simulations[3] for a TAE with toroidal mode number $n=4$. The effects of damping location, plasma density gradient, and bulk plasma pressure profile on continuum damping are investigated.

1. Effect of density profile on continuum damping

Since the local Alfvén velocity depends on density, the Alfvén continuous spectra depend on the density profile. When the density decreases towards the plasma edge, the frequency of the Alfvén continuum rises and the continuum damping occurs. In the simulations, the parameter r_{trans} controls the position of density decrease and Δr controls the density gradient as shown in Fig. 1.

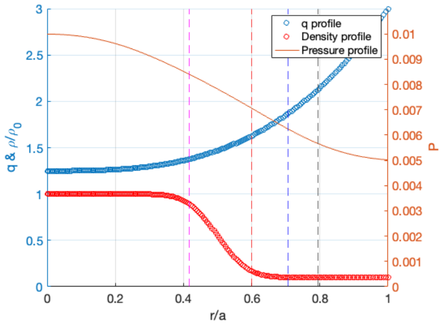

Figure 1. Spatial profiles of safety factor (q), density with r_{trans}=0.5 and Δr=0.1, and pressure.

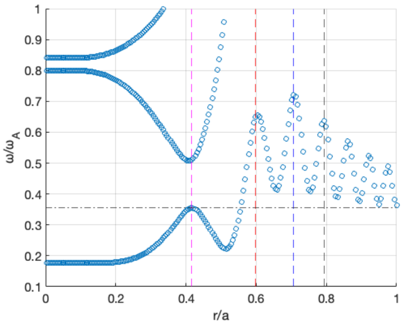

Figure 2. Alfvén continua for the density profile with r_{trans}=0.5 and Δr=0.1 shown in Fig. 1. The TAE frequency is represented by horizontal line.

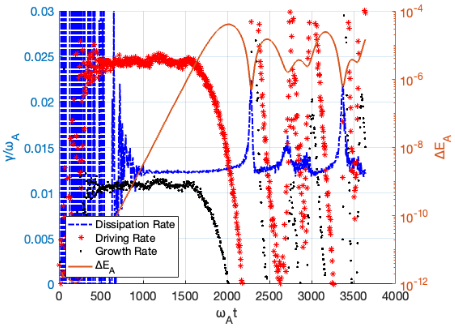

Figure 3. Time evolution of energy (ΔE_A), energy dissipation rate, driving rate, and growth rate for r_{trans}=0.5 and Δr=0.1.

The Alfvén continua are shown in Fig. 2 for the density profile shown in Fig. 1. We see in Fig. 2 that the frequency of the TAE intersects with the Alfvén continuum. We expect that the continuum damping occurs. The time evolution of energy dissipation rate of the TAE is shown in Fig. 3 for the density profile shown in Fig. 1. The energy dissipation rate normalized by the Alfvén frequency is 1.231% which is higher than that for the uniform density 1.067% and demonstrates the continuum damping for the decreasing density profile. The continuum damping is enhanced with closer damping location to the TAE. Steep density gradient also enhances the continuum damping. The energy dissipation rate of the TAE normalized by the Alfvén frequency is 1.531% for a steep density profile with r_{trans} =0.5 and Δr=0.05.

2. Effect of uniform pressure

Continuum damping for the uniform bulk plasma pressure is stronger than that for the decreasing pressure profile. For a uniform bulk plasma pressure 0.25% normalized by B_0^2/μ_0 , the normalized energy dissipation rate is 1.692% which is higher than 1.531% for the gradually decreasing pressure profile. We found that higher uniform bulk plasma pressure results in stronger continuum damping.

3. Dependence on radial gradient of Alfvén continuum frequency

We plot in Fig. 4 the continuum damping rate versus the radial gradient of Alfvén continuum frequency for the simulations we performed. The continuum damping rate is defined by the increase in energy dissipation rate from that for the basic case without continuum damping. It is demonstrated by the simulations that the continuum damping is stronger for the larger spatial gradient of the Alfvén continuum frequency.

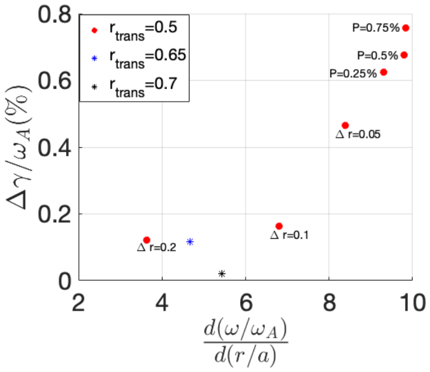

Figure 4. Continuum damping rate versus radial gradient of Alfvén continuum frequency.

Conclusion

We investigated the continuum damping of TAEs in tokamak plasmas with kinetic-MHD hybrid simulation. The following properties were found for continuum damping:

- Continuum damping is enhanced with closer damping location to the TAE.
- Steep density gradient and uniform bulk plasma pressure enhance the continuum damping.

The simulation results demonstrated that continuum damping of TAE is stronger for larger spatial gradient of the Alfvén continuum frequency. Continuum damping rate converges to a constant level for weak dissipation. These results may contribute to the control of the TAEs in tokamaks.

References

[1] W. W. Heidbrink, 2008, Physics of Plasmas, 15 055501.

[2] Heyvaerts, J., Priest, E. R.,1983, Astronomy and Astrophysics, 117(2):220-234.

[3] Y. Todo, 2006, Phys. Plasmas, 13 082503.