Simulations of nonlinear interaction between beta-induced Alfvén eigenmode and tearing mode

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The Alfvén eigenmodes (AEs) driven by energetic particles (EPs) can cause redistribution and losses of EP. Representatively, the beta-induced Alfvén eigenmode (BAE), which exist in the continuum gap caused by the finite thermal plasma compressibility. Meanwhile, the tearing mode (TM) also often exist in tokamak plasmas, which can creat magnetic islands and even trigger disruptions. In addition, the nonlinear interaction/coupling of AEs and TM are observed frequently in many tokamak experiments and have been widely studied[1,2,3]. However, the nonlinear interactions are highly complex with rich physics and need to be understood synthetically[4].

Figure 1 shows the experiment observation for HL-2A shot #30759, the frequency of n=0 component is slightly lower than that of BAE, and it is comparable to the difference of BAE and TM ($\omega = \omega_{\mathrm{BAE}} - \omega_{TM}$), which reveals a nonlinear mode coupling process between BAE and TM. By using the kinetic-MHD hybrid code M3D-K, we perform the numerical simulations to explore the underlying mechanisms of the nonlinear interactions referring m/n=2/1 BAE, m/n=2/1 TM and EPs.

It is found that the TM activity can have a destabilizing effect on the energetic particle-driven BAE. For BAE linearly-dominant-unstable case, the TM activity results in the inward movement of BAE mode structure. For BAE linearly-stable case, due to the redistribution of energetic ions induced by TM, the increased radial gradient of energetic ions distribution near 2/1 island separatrix leads to the excitation of BAE. The energetic ions are strongly redistributed by the coexistence of BAE and TM. Furthermore, a high-frequency m/n=0/0 ($\mathrm{n}_{0,HF}$) component is excited by the nonlinear mode coupling between 2/1 BAE and 2/1 TM, which is consistent with the experiment observation, and it's mode structure of perturbed parallel current $\Delta\mathrm{C}$ is mainly located inside 2/1 magnetic island with amplitude exhibiting a high-frequency periodic oscillation.

Finally, this $\mathrm{n}_{0,HF}$ component leads to a synchronized periodic oscillation of 2/1 magnetic island width, and the mode structure of BAE and TM exhibits a correspondingly periodic variation between overlapping and separating. The change rate $\Delta\mathrm{W}$ of island width oscillation is dependent on the strength of $\mathrm{n}_{0,HF}$ component, and a larger $\Delta\mathrm{W}$ can more easily to cause the overlapping of neighbouring magnetic island and then trigger the plasma disruption. In addition, the 3/1 magnetic island width remains almost unchanged without $\mathrm{n}_{0,HF}$ component around q=3 rational surface in the nonlinear stage.

References
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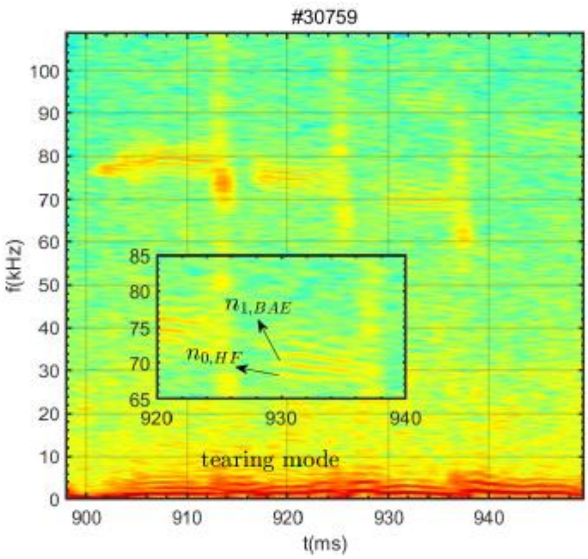

Figure 1. The MHD instabilities (including n=1 BAE, n=1 TM and the high-frequency n=0 component) for HL-2A shot #30759.

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