6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

Global kinetic-MHD simulations of downsweeping reversed shear Alfvén eigenmodes in tokamak plasmas

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Reversed shear configuration is to apply for the steady-state operation in advanced tokamak scenarios. In such configuration, reversed shear Alfvén eigenmodes (RSAEs) can be destabilized by energetic particles. In experiments, downsweeping RSAEs destabilized by energetic electrons were observed during the transition phase from TAEs to normal RSAEs. Despite experimental observations and theoretical analysis, few simulation works have focused on the effects of specific physical conditions and experimental parameters on the excitation of downsweeping RSAE instability. Hybrid simulations are performed to investigate the dependence of downsweeping RSAEs on key parameters in tokamaks using global kinetic-MHD hybrid code M3D-K. The slow frequency evolution of the downsweeping and upsweeping RSAE sweeping process in experiments is reproduced by a set of simulation, changing only the equilibrium q-profile.

In this work, the downsweeping RSAE, for which it has been confirmed that the mode is in the nonperturbative regime, has a twisted mode structure in the poloidal plane, while the upsweeping RSAE, which is weakly affected by the energetic ion effects, has a nearly up–down symmetry mode structure, as shown in Fig. 1. Further, downsweeping RSAEs, showing a relatively narrow mode spatial profile, are generally more stable than the upsweeping ones, which can be a reason why the downsweeping RSAEs are rare in experiments. By analyzing key plasma parameters, we find that the excitation condition of downsweeping RSAEs is more stringent than that of upsweeping modes, especially for bulk pressure gradient at $q_{\min}$ and the magnetic shear strength in the central region. The enhancement of the pressure gradient at $q_{\min}$ improves the likelihood of the destabilization of downsweeping RSAEs. Moreover, the downsweeping RSAEs only occur in a weak magnetic shear configuration in our simulations. It is found that the downsweeping RSAEs can be replaced by TAEs with increasing negative magnetic shear. Finally, it is found that the kinetic effect of the energetic ion central pitch angle does not affect the excitation of downward-sweeping RSAEs, but affects the mode stability. One of the main results is shown in Fig. 2.

References

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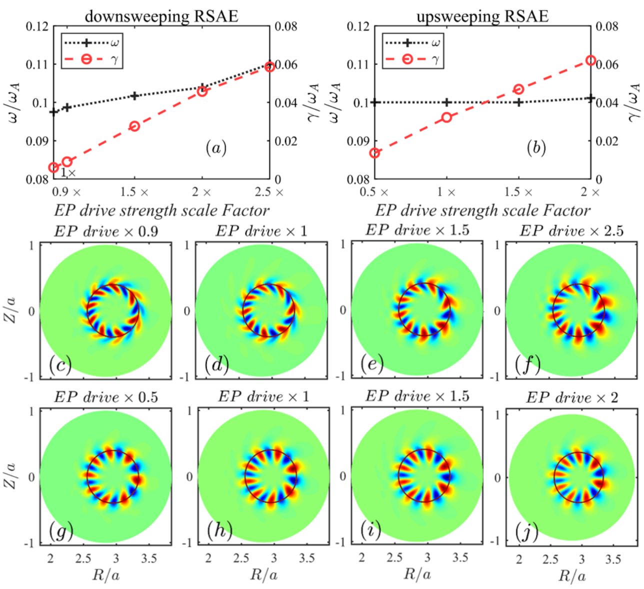

Fig. 1. Linear mode frequency and growth rate varies with energetic ion drive strength for (a) downsweeping and (b) upsweeping RSAE. The mode structure varies with energetic ion drive strength for (c)–(f) downsweeping RSAE and for (g)–(j) upsweeping RSAE.

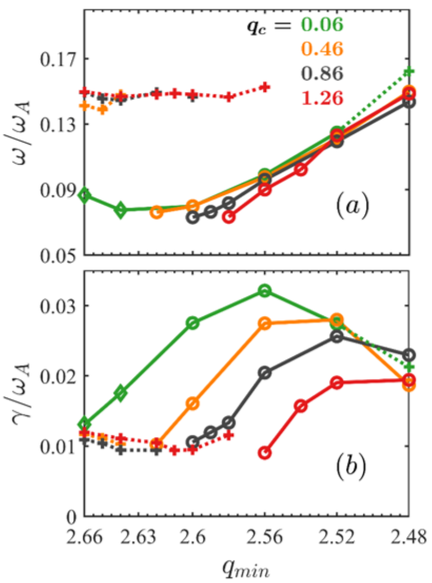

Fig. 2. (a) Frequencies and (b) growth rates vary with $q_{\min}$ for different negative magnetic shear q_c, where $q_c = q_0 - q_{\min}$. The diamonds, circles, and crosses correspond to the downsweeping RSAEs, upsweeping RSAEs and TAEs, respectively.