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Nonlinear simulations of Alfvén eigenmodes in CFQS plasmas

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Quasi-axisymmetric (QA) device combines the advantages of both tokamak and stellarator, and thus, it can be considered as a disruption-free tokamak and it excites the interests of the fusion community. Alfvén eigenmode (AE) is an important issue for magnetic confinement fusion because it enhances energetic particle (EP) transport and degrades heating performance. Nowadays, a QA device named CFQS is being constructed, and the first plasma will be generated soon. Thus, the research of EP-related instabilities in QA configuration becomes significant and urgent.

The simulation is conducted using MEGA code which is a hybrid simulation code for EPs interacting with a magnetohydrodynamic (MHD) fluid. The equilibria are calculated using HINT code with bootstrap currents 20 kA and 5 kA, respectively. In the 20 kA bootstrap current case, 6 islands appear on the edge, while in the 5 kA bootstrap current case, the islands disappear and the magnetic field on the edge region becomes stochastic.

The instability in CFQS in three-dimensional form is shown for the first time. Both global Alfvén eigenmode (GAE) and toroidal Alfvén eigenmode (TAE) are found in CFQS with and without magnetic island. The dominant mode numbers are $m/n = 3/1$ for GAE and $m/n = 5/2$ for TAE. Strong mode coupling is found under the condition of a very low field period N_{fp} value. This result is consistent with theoretical prediction, and it is similar to the simulation of FAR3d code. For GAE, the mode frequency 79 kHz does not depend on energetic particle pressure or energetic particle beam velocity, while the growth rate increases with energetic particle pressure, and the growth rate is maximum for the energetic particle beam velocity of $0.5v_A$ where v_A is Alfvén velocity. For TAE, similarly, the mode frequency 125 kHz does not depend on energetic particle pressure, energetic particle beam velocity, or peak value of energetic particle pitch angle. The growth rate increases with energetic particle pressure, roughly decreases with the increasing of the peak value of energetic particle pitch angle, and the growth rate is maximum for the energetic particle beam velocity of $0.5v_A$. The resonant condition $f_{mode} = nf - lf$ is confirmed. For GAE, $n = 1$ and $l = 2$, and for TAE, $n = 2$ and $l = 4$. Nonlinear simulation results of AE in CFQS are shown for the first time. GAE frequency chirps in the nonlinear saturated phase, and TAE is similar to that. Hole and clump structures are formed in the pitch angle and energy phase space. The particles comprising the hole and clump are kept resonant with the GAE or TAE during the mode frequency chirping. Finally, during the mode activities, energetic particles are lost from the core region. For the present simulation, the transport caused by GAE is stronger than that of TAE.

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