Optimization of the Alfven Eigenmodes and Energetic Particle Mode stability in nuclear fusion devices using a Landau-closure model

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ABSTRACT

The aim of this study is to analyze the stability of Alfven Eigenmodes (AE) and energetic Particle Modes (EPM) in magnetic confinement devices, identifying optimization trends to improve the heating efficiency of future nuclear fusion devices.

The EP can generate instabilities enhancing the transport of fusion produced alpha particles, energetic neutral beams and ion cyclotron resonance heated particles (ICRF), reducing the heating efficiency in nuclear fusion devices. AE are driven in the spectral gaps of the shear Alfven continua. The AE belong to different families linked to the frequency gaps produced by periodic variations of the Alfven speed. In addition, EPM can be unstable for frequencies in the shear Alfven continua if the continuum damping is not strong enough to stabilize them.

We use the gyro-fluid code FAR3d to calculate the stability of the AE/EPM. The code solves a reduced set of equations retaining the toroidal angle variation, based upon an exact three-dimensional equilibrium that assumes closed nested flux surfaces. The effect of the energetic particle population in the plasma stability is included through moments of the fast ion kinetic equation truncated with a closure relation, describing the evolution of the energetic particle density (n_f) and velocity moments parallel to the magnetic field lines ($v_{\parallel f}$). The model includes the effect of the acoustic modes, finite Larmor radius for thermal ions and energetic particles, Landau damping for electrons and ions, multiple EP populations, diamagnetic currents and EP trapping. The Landau damping and resonant destabilization effects are added by a closure relation. The main advantage of using gyrofluid FAR3d code regarding gyrokinetic codes is the simulation time. The scale time of a single processor FAR3d simulation is minutes compared to weeks or months in the case of multiprocessor gyrokinetic runs, allowing carrying out parametric studies, identifying configurations with improved AE/EPM stability.

The simulations for the JT-60SA ITER-like inductive scenarios show the possible destabilization of a 3/2-4/2 TAE with a frequency of 115 kHz, a 6/4-7/4 TAE with f=98 kHz and a 6/4 or 7/4 BAE with f=57 kHz. If the energetic particle β increases, BAE, TAE and EAE are destabilized between the inner-middle plasma region, leading to multiple AE of different toroidal families in the same plasma region. If these instabilities coexist in the non-linear saturation phase the EP transport could be enhanced leading to a lower heating efficiency by the N-NBI. For a hypothetical configuration based on the ITER-like inductive scenario but an on-axis N-NBI injection, the EP β threshold increases and several BAEs are destabilized in the inner plasma region, indicating an improved AE stability with respect to the off-axis case. In addition, the analysis of a hypothetical JT-60SA scenario with a resonant q=1 in the inner plasma region shows the destabilization of fishbones-like instabilities by the off-axis N-NBI. Also, the N-NBI driven EPs have a stabilizing effect on the RBM, stronger as the population of EP with low energies (below 250 keV) increases at the plasma pedestal.