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High-order coupling of shear-Alfvén and acoustic continua in JET plasmas

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Unstable Alfvén eigenmodes (AEs) are a key issue in magnetically confined fusion, both for currently operating machines (JET, AUG, etc) and for next step devices such as JT60-SA and ITER, due to their potential to cause energetic-ion (heated by NBI/ICRH or fusion alphas) redistribution and losses [1,2]. Toroidicity-induced AEs (TAEs), resulting from the coupling of two shear-Alfvén waves, are one of the most extensively studied Alfvénic instabilities in tokamaks [1,2]. However, lower-frequency AEs (i.e., $\omega < \omega_{tae}$) have been observed in DIII-D high-beta plasmas under intense NBI, associated with large energetic-ion loss levels, much similar to those caused by TAEs [3,4].

In this contribution, we report and discuss Alfvénic activity observed at JET, at about half the TAE frequency (figure 1), in plasmas heated by NBI and ICRH [5]. AEs with frequencies lower than the TAEs have been previously explained by the beta-induced coupling of shear-Alfvén and acoustic waves (BAAEs), via the lowest-order harmonic of the field-line geodesic curvature [6,7]. However, their expected frequency $\omega_{baae} \sim 2\beta^{1/2}\omega_{tae}$ is too low to explain the measured eigenfrequencies on JET. Here, we show that the experimental measurements can be explained by the previously unexplored gaps in the frequency of shear-Alfvén and acoustic continua. In the vicinity of these gaps, several acoustic waves couple to a single shear-Alfvén wave via higher-order harmonics of the geodesic curvature caused by the plasma shaping and, in particular, the elongation of JET plasmas [8]. In the limit of plasmas with circular magnetic surfaces, the proposed model reduces to the well-known lowest-order coupling. New frequency gaps are predicted at integer multiples of ω_{baae}, but only under certain conditions imposed by the local shaping parameters and a limiting value of the safety factor [8].

The continuous spectra computed with the compressible ideal-MHD code CASTOR display the predicted frequency gaps, which open where acoustic branches cross with the up-shifted shear-Alfvén branch (figure 2). Although quite narrow, such gaps allow the existence of global AEs whose radial structure and frequency is also computed with CASTOR (figure 2). In this contribution, the computed AE radial location and frequency are shown to be in fair agreement with experimental data, the latter within a few percent of measured values and the former matching soft x-ray observations.

The proposed high-order geodesic acoustic eigenmodes (HOGAEs) were found to be driven unstable by energetic-ion populations with characteristics similar to those accelerated by ICRH (figure 3), with a temperature around 1 MeV and on-axis density about 1% of the value corresponding to the thermal ions [8]. In this contribution, their stability in JET plasmas will be evaluated with the hybrid MHD/drift-kinetic code CASTOR-K, taking into account energetic-ion populations heated by NBI and ICRH, their distributions functions being computed, respectively, by the codes ASCOT and PION. Wave-particle resonances, along with drive/damping mechanisms, will also be discussed. Amplitude saturation levels and mechanisms will be addressed with the non-linear code POLARIS-K. Overall, the presented results will allow a better understanding of HOGAEs role in energetic-ion redistribution and losses and their potential impact on the operation of next step devices like JT60-SA and ITER.

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