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Stabilization of Alfvén Eigenmodes in DIII-D via Controlled Energetic Ion Density Ramp and Validation of Theory and Simulations[1]

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Alfvén eigenmodes with frequency close to the ion cyclotron frequency ($f = 0.58\ f_{ci}$) are stabilized via a controlled energetic ion density ramp for the first time in a fusion research plasma. The particle injection rate of a neutral heating beam is slowly decreased while holding particle energy constant in a low field ($B_T = 1.28$T) DIII-D discharge. A mode is abruptly stabilized as the injection rate crosses below a critical threshold, providing a controlled demonstration of the competition between fast-ion drive and wave damping processes. The mode amplitude scaling with injection rate is consistent with the theoretical scaling for single mode collisional saturation near marginal stability, notably weaker than the previously established scaling from simulations of GAEs in the collisionless regime and far from marginal stability. Analysis of the fast-ion population shows that the mode is driven by anisotropy in the distribution for a Doppler-shifted cyclotron resonant (DCR) high-energy subset of the fast ions. The mode is identified as a shear-polarized global Alfvén eigenmode (GAE) via the measured frequency in conjunction with AE dispersion relations and the resonance condition for fast-ion drive. This is the first identification of a DCR GAE in a conventional aspect ratio tokamak ($R/a > 2$). The measured frequency of the mode agrees with predictions of linear theory for DCR AE stability [Lestz, PoP 2020] and simulations using the hybrid MHD code HYM [Belova, PRL 2015]. Both models predict DCR GAEs to be the most unstable modes for these plasma conditions and fast-ion distribution in this frequency range. Measurements of the GAE density perturbation show the mode is core localized with a broad spatial structure, as seen in HYM simulation. These results are a significant advance in predictive capability for DCR instabilities in fusion plasmas.

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