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EXPERIMENTAL AND COMPUTATIONAL INVESTIGATIONS OF ALFVÉN EIGENMODE STABILITY IN JET PLASMAS THROUGH ACTIVE ANTENNA EXCITATION

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INTRODUCTION

Understanding the interaction of Alfvén Eigenmodes (AEs) and energetic particles, namely fusion alphas, is of utmost importance to the operation and performance of future tokamaks, such as ITER and SPARC. In the JET tokamak, a toroidal array of eight in-vessel antennas was installed 1 to actively excite stable AEs with frequencies ranging 25 –250 kHz, typical of BAEs, RSAEs, and TAEs in JET. Independent phasing of each antenna allows AEs with low to intermediate toroidal mode numbers, |n| < 10, to be probed; this is a significant improvement over previous studies conducted with saddle coils 2 limited to |n| < 2 (and frequencies > 60 kHz). During the 2019 JET deuterium campaign, over 5000 resonances were actively excited –and their frequencies ω_0, damping rates γ, and toroidal mode numbers measured –in over 500 JET plasmas. A large database of these parameters has been populated, from which new physics can be extracted and compared with MHD and gyrokinetic simulations. Similar measurements are expected in the upcoming JET hydrogen and tritium campaigns, and these data will help prepare for operation in the DT campaign.

DAMPING RATE MEASUREMENTS FOR LARGE FAST ION POPULATIONS

Recent JET experiments have seen record NBI heating powers over 32 MW, and stable AEs have been resonantly excited at total heating powers (NBI + ICRH) up to 35 MW. Damping rate measurements γ/ω_0 at such high power allow the investigation of AE driving and damping mechanisms in the presence of large fast ion populations. Latest observations are shown in Fig. 1 as probability density functions, constructed assuming each measurement is Gaussian with mean equal to γ/ω_0 and standard deviation equal to the associated uncertainty. While the effects of fast ion drive and Landau damping must be untangled from the dataset, lower damping rates are observed more often during NBI and ICRH. Though not shown here, it is found that γ/ω_0 decreases with increasing plasma current and density and depends on the magnetic configuration (e.g. limiter vs x-point, elongation, triangularity, etc.).

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INTERMEDIATE TOROIDAL MODE NUMBERS AND THE FAST ION PRESSURE GRADIENT

This work extends the previous JET AE database [3] to intermediate toroidal mode numbers, |n| ˜ 5 –7, which are those predicted to interact most strongly with fusion alphas in JET [4]. Measurements of unstable AEs indicate the existence of modes with |n| ≤ 7, although higher |n| ˜ 20 can be resolved by the magnetics. Comparisons of toroidal mode numbers with opposite signs can assess the fast ion drive since its destabilization term is proportional to n while no other damping effects depend on the sign of n [5]. In this dataset, there are over 25 observed modes with 5 ≤|n|≤ 7 in plasmas with total heating power (NBI + ICRH) ranging 5 –30 MW.

COMPUTATIONAL STUDIES OF TOROIDAL AND BETA-INDUCED ALFVÉN EIGENMODES

Computational studies of AE stability have been performed using both MHD and gyrokinetic codes. Recent work [6] reported the damping of TAEs during high NBI power in JET, and the MHD code MISHKA [7] confirmed the core-localization of TAEs during ICRH heating. A complementary study [8] simulated both stable and destabilized TAEs in JET with the gyrokinetic code GTC [9], quantifying the dominance of ion Landau and radiative damping over continuum and electron Landau damping. Comparisons between experimentally-measured and GTC-predicted damping rates are in good agreement, as seen in Fig. 2. Additional GTC simulations are being performed to quantify (i) the drive from the ICRH minority ion population and (ii) the damping due to NBI, for TAEs with n = 4, 5, and 6. Moreover, GTC is being used for the first time to characterize experimentally-observed low n, low frequency modes –postulated to be BAEs –and determine their radial mode structure. Preliminary results indicate that modes with n = 2, 3, and 4 can be driven by an experimentally-relevant fast ion population.

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