Alfvén cyclotron instabilities in D and H-D plasmas on MAST

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Alfvén cyclotron instabilities driven by energy gradients of fast ions have been observed as Ion Cyclotron Emission on major conventional tokamaks [1-5], and as Compressional Alfvén Eigenmodes (CAEs) and Global Alfvén Eigenmodes (GAEs) on spherical tokamaks NSTX [6] and MAST [7]. These instabilities are of interest for diagnosing fusion products, and they may affect the efficiency of a beam current drive by causing a pitch-angle scattering higher than Coulomb collisions. In view of deuterium-tritium (DT) operation required for burning plasmas, studies of Alfvén cyclotron instabilities in plasmas with two main bulk ion species are highly relevant.

Dedicated experiments on Alfvén cyclotron instabilities in plasmas consisting of two main ion species with unequal cyclotron frequencies were performed on MAST. Super-Alfvénic D beam with energy $E_b \approx 70$ keV was injected into MAST hydrogen-deuterium (HD) plasmas at low magnetic field, $B_T(0) \approx 0.31T$ - $0.44T$. All the discharges had the same scenario, with H/D concentration being the only parameter varied. In pure D plasmas, Alfvén instabilities were excited over a broadband frequency range, up to $\sim 3.5$ MHz, with two distinct classes of modes: 1) sub-cyclotron modes with frequencies from $\sim 500$ kHz to $\sim 1$ MHz, and propagating in counter-NBI, counter-current direction (toroidal mode numbers $n<0$), and 2) modes with frequencies from $\sim 500$ kHz to $\sim 3.5$ MHz, and $n>0$. The second class of modes has large frequency separation, $\sim 150$-$230$ kHz, between modes of different $n$’s, and since the highest frequency of these modes exceeds D cyclotron frequency, the modes are identified as CAEs. Plasmas with range of H/D concentrations from 0% to $>60\%$ were produced, and the H/D concentration was diagnosed by using i) $H_\alpha/D_\alpha$ intensity ratio, ii) fission chamber measuring neutron rate from D-D reactions, and iii) neutron camera with four lines-of-sight at different radial positions. In MAST discharge with highest H concentration, modes were detected at a record high frequency of $\sim 4.5$ MHz, which is close to hydrogen cyclotron frequency, $\omega \approx \omega_{BH}$.

It was observed that at increasing H/D concentration, CAEs are suppressed. The suppression effect on CAE is especially strong (CAE disappear) in the frequency range between cyclotron frequencies of deuterium and hydrogen, $\omega_{BD} \leq \omega \leq \omega_{BH}$, where the ion-ion hybrid resonance could provide a strong damping. Similar effect of CAE suppression in the frequency range between cyclotron frequencies of tritium and deuterium, $\omega_{BT} \leq \omega \leq \omega_{BD}$, is expected for DT plasmas. In this work, description of the MAST experimental data will be given and modelling of CAEs performed for D and HD discharges on MAST. This work was part-funded by the RCUK Energy Programme and by the European Union’s Horizon 2020 programme.