Applications of Three-Ion ICRF Heating for ITER

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Recently, a new set of three-ion minority ICRF (ion cyclotron range of frequencies) heating scenarios has been identified [1, 2]. A distinct feature of these scenarios is the high efficiency of RF power absorption at very low concentrations of resonant ions (~ 1% and even below). This is achieved by adjusting the concentration of the two majority ion species to maximize the left-hand component of the RF electric field in the region of the cyclotron resonance of a third (minority) species.

Three-ion ICRF scenarios are also relevant for the experimental programme of ITER. During the full-field non-activated phase of ITER operation, injecting a small amount of ^{3}He ions into H-^{4}He mixtures is a promising ICRF scenario for effective plasma heating. The (^{3}He)-^{4}He-H scenario would minimize the ^{3}He consumption in ICRF-heated plasmas. Concentrations of n_{3He}/n_e as low as ~0.1% in plasmas with $n_H/n_e \sim 70\%$ are sufficient for effective RF power absorption by ^{3}He ions. As a result of the high RF power per resonant particle, MeV-range ^{3}He ions can be generated with this ICRF heating scenario in ITER. This technique of ion acceleration can be used to mimic the behaviour of energetic alpha particles already during the no-neutron ITER phase.

Channelling ICRF power to intrinsic beryllium impurities in D-T plasmas is another promising three-ion scenario. For the same amount of coupled ICRF power, calculations show that the (^{9}Be)-D-T scenario should provide a larger fraction of bulk ion heating (D and T) than the commonly considered scenario using ^{3}He as a minority [2]. The proposed method is useful for the ramp-up phase of ITER D-T pulses and is not restricted to the use of ^{9}Be only: other impurities with a similar charge-to-mass ratio, such as ^{7}Li (which was observed during initial D-T experiments on TFTR [3]), ^{22}Ne, and ^{40}Ar, can be used as well.

Initial studies on the potential of three-ion ICRF scenarios were undertaken in H-D plasmas on Alcator C-Mod in the Fall 2015 campaign [4, 5]. Strong plasma heating was observed during these experiments where the estimated n_H/n_e was 56–66% and $n_{3He}/n_e \sim 0.4$–2%. At low ^{3}He concentrations, Alfvén eigenmode activity was detected. Triggering Alfvén eigenmodes in $B_0 \sim 8$T C-Mod plasmas is consistent with the expected acceleration of ^{3}He minority ions to high energies exceeding 1 MeV due to three-ion (^{3}He)-D-H absorption.

This paper also includes a discussion of the applicability of these ICRF scenarios for other fusion machines (W7-X, AUG, JET). Finally, in the context of three-ion ICRF development, we discuss the possibility of using fast ions generated by neutral beam injection (NBI) as resonant absorber (third ion) species. Experiments for ICRF heating of D beam ions in H majority plasmas, (D_{NBI})-D-H have been suggested for the forthcoming H campaign on JET.

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