PLASMA INITIATION AND STARTUP STUDIES IN THE DIII-D TOKAMAK WITH SECOND HARMONIC EC ASSIST*

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Second harmonic X-mode (X2) electron cyclotron (EC) heating has been used in DIII-D to examine plasma initiation and burnthrough of low Z impurities. Although the toroidal inductive electric field (E_ϕ) in DIII-D is high enough (0.9–1.0 V/m) to allow robust startup without EC assist, startup in superconducting devices such as ITER will have lower fields (E_ϕ = 0.3 V/m) and EC assist can provide an increased margin for burnthrough of low Z impurities. In addition, the use of EC heating for plasma initiation allows for a wider range of acceptable pre-fill neutral pressure and magnetic field errors. Experiments in the DIII-D tokamak have demonstrated X2 pre-ionization and plasma startup under a variety of conditions, $1.13 < R_{X2} < 1.85$ m, $0 < B_{z,\,applied} < 40$ G, and $0.04 < P_{Deuterium} < 0.28$ mTorr, where R_{X2} is the X2 resonance radius ($R_{0,DIII\text{-}D} = 1.67$m). A visible bremsstrahlung (VB) array confirms that the initial ionization occurs at or near the second harmonic major radius under all conditions and rapidly expands to fill the vessel volume. With EC heating, plasma current formation is prompt and burnthrough of low Z impurity charge states is earlier in time. The power threshold for breakdown using 2nd harmonic heating with the nominal DIII-D breakdown algorithm to maximize magnetic field connection length, $L_{connect}$, is approximately 0.8 MW. However this power threshold actually decreases, up to a factor of three, as a programmed vertical field is applied (smaller $L_{connect}$). Pre-ionization was strongest for EC perpendicular launch ($k_{||} = 0$), and only occurred for small angles (±10 deg.) about perpendicular. Although X2 heating efficiency is low for cold electrons, an orbit following code ($k_{||} = 0$) predicts that room temperature electrons can be heated to >50 eV within the EC heating volume in DIII-D. This is well above the ionization threshold, 20 eV, for ionization of hydrogen[1].

Fundamental EC heating is planned for ITER (B_ϕ = 5.3 T). Nevertheless a qualitative assessment of EC startup can be made in DIII-D using X2 EC heating if R_{X2} is inside the plasma volume. An ITER-like large volume startup scenario initially limiting on the low field side has been developed in DIII-D. Using a lower inductive voltage, $E_\phi \approx 0.6$ V/m, burnthrough was faster when compared to ohmic discharges with the same E_ϕ. This scenario, when applied to ITER, would place the O1 resonance of the main heating gyrotrons (170 GHz) within the ITER plasma volume during the burnthrough phase, providing sufficient power for burnthrough assist under a variety of conditions.

[1]A. von Engel, *Ionized Gases*,1955, (Oxford: Clarendon)

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