Topic : EX-C

Quasi-Vertical Launch Third Harmonic Electron Cyclotron Resonance Heating of H-mode on TCV

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The Tokamak à Configuration Variable (TCV) is equipped with three 480kW gyrotrons operating at 118GHz. They launch radiation in the extraordinary mode (X-mode) allowing plasma heating using third harmonic X-mode electron cyclotron resonance heating (X3) at density up to $\approx 11\times10^{19}m^{-3}$. The X3 system [1] was designed to achieve high plasma-β, to heat ions through electron-ion collisions and to enlarge the operational space of H-mode on TCV.

The gyrotron radiation is transmitted to the tokamak along three evacuated waveguides. At the tokamak the radiation is projected onto one plasma facing mirror that can be translated radially between discharges and rotated poloidally during a discharge. Using these two degrees of freedom the launch geometry is optimised for a given plasma scenario. The 3^{rd} harmonic X-mode is not optically thick and so a quasi-vertical launch is used to maximise first pass absorption. TORAY-GA [2] is used to estimate the X3 coupled power and Arnoux [3] has shown this to be reliable for X3 in TCV H-modes.

Experiments have been performed to heat H-mode using X3. The target, for these experiments, was an ohmic H-mode chosen for its reproducibility, robustness and for its electron density close to optimal for X3. The discharges were diverted with plasma current, $I_{p,} \approx 400$kA while the maximum plasma density was typically $\approx 7\times10^{19}m^{-3}$. The toroidal field, B_o, was 1.45T, plasma elongation, κ, ≈ 1.75 and the triangularity, δ, ≈ 0.52. The stored energy was ≈ 20kJ and the power loss per ELM was ≈ 4%. The ion grad-B drift was away from the X-point. Up to ≈ 90% of the launched X3 power was coupled to the plasma so that the total heating power (≈ 1.5MW) was much greater than the ohmic H-mode threshold power (≈500kW). The radiated power was ≈ 300kW during the X3 heated phase.

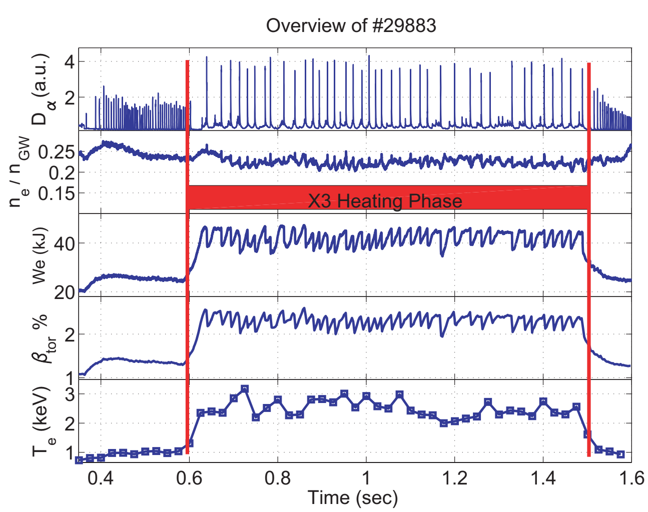

Figure 1; overview of TCV shot #29883

Typically the X3 heated H-mode discharges entered a large ELMy regime where the energy loss per

ELM increased to ≈ 12%. The electron temperature increased from ≈ 1keV to ≈ 3keV and the stored energy and plasma β were both nearly doubled. The energy confinement time in the large ELM phase was up to ≈ 25msec ($H_{IPB(y,2)} \approx 1.3$) [4] and the high confinement was maintained for ≈ 30 confinement times. Figure 1 shows such an example. In these experiments the total heating power was nearly three times the H-mode threshold power suggesting that the large ELMs were probably Type I [5].

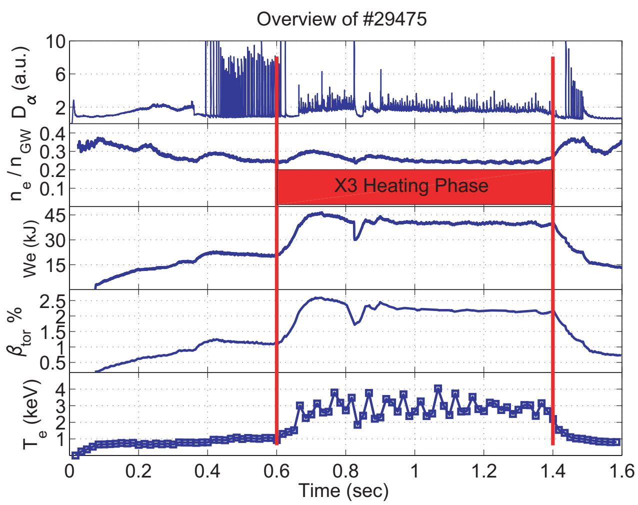

Figure 2: overview of TCV shot #29475, a quasi-stationary ELM free H-mode

On other occasions with ostensibly the same X3 launch geometry and the same plasma target, and for reasons as yet not understood, the X3 heated H-modes transited into an ELM free H-mode regime with constant electron density and stored energy. Figure 2 gives an overview of such a discharge. In this shot, instead of entering the large ELM regime, the discharge entered a regime of elevated D_α recycling light and elevated confinement. During the X3 phase the stored energy and β_{tor} both doubled while the electron density remained approximately constant. The maximum, achieved β_{tor} was ≈2.5% while the ideal β-limit for these discharges was ≈3.5%. The recycling light level was high compared to the baseline ohmic H-mode level and the fluctuations in the D_α light was correlated with core MHD. Typically m/n = 4/3 tearing modes were associated with the quasi-stationary ELM-free H-mode. The confinement time for these discharges was found to be as high as ≈ 30ms ($H_{IPB(y,2)} \approx 1.7$). In the ELM-free regime it was possible to make measurements of carbon ion temperature profiles and carbon rotation velocity using charge exchange recombination spectroscopy. During the quiescent H-mode phase the ion temperature at normalised radius, ρ ≈ 0.6, increased from ≈ 500eV to ≈ 1keV. The plasma rotation increased also: at the same minor radius the rotation velocity increased from ≈ 5kms^{-1} to ≈ 50kms^{-1}.

References

[1] J.-Ph. Hogge, S. Alberti, G. Arnoux, L. Porte; Nucl. Fusion **43** (2003) 1353

[2] K. Matsuda; IEEE Proc. Plasma Sci. 17 (1989) 6

[3] G.A. Arnoux; ‘Chauffage de Plasma Par Ondes Électromagnétique à la Troisième Harmonique de la Fréquence Cyclotron des Électrons dans le Tokamak TCV’ ; PhD Thesis submitted to the École Polytechnique Fédérale de Lausanne 2005 ; Thèse #2401 (2005)

[4] ITER Physics Expert Groups on Confinement and Transport and Confinement Database; Nucl. Fusion **39** (1999) 2175

[5] J.W. Connor; Plasma Physics and Controlled Fusion **40** (1998) 531