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3^{rd} Harmonic ECH on TCV using Vertically Launched 118GHz Radiation

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ABSTRACT

The TCV electron cyclotron resonance heating (ECRH) system has been upgraded with the addition of three 118GHz, 500kW gyrotrons. They are designed to heat at the 2^{nd} harmonic (n=3) of the cyclotron resonance using extraordinary mode (X-mode) radiation. Vertical launch geometry is used to maximize the path length along the resonance. The plasma facing mirror is on the top of the machine. Real-time control of the poloidal launch angle has been installed and is being commissioned. The X3 system enables the heating of high density ($\leq 1.1\times10^{20}$ m^{-3}) plasma. Attempts have been made to heat the core plasma of H-mode discharges on TCV. This paper will briefly describe the X3 heating system and the real-time mirror control system. Initial results from the heating of H-mode will be presented

THE X3 HEATING SYSTEM

The entire X3 system is described by J.P. Hogge et al [1]. Three gyrotrons operate at 118 GHz and each radiate ≈480 kW. A matching optics unit (MOU) is used to set the polarisation and ellipticity of the gyrotron beam. The output, from each gyrotron, is transmitted to the tokamak or a calibrated load along ≈40m of evacuated corrugated waveguide. Each gyrotron has its own transmission line. The three separate waveguides converge on a single launch mirror that has a focal length of 700mm and is made of copper. The beam waist radius in the plasma is ≈3cm. The mirror can be translated, between shots along a major radius between 800mm and 965mm and can be rotated poloidally, during a shot, in the range 40^o to 50^o.

REAL-TIME CONTROL OF THE LAUNCHER MIRROR

The optimum electron density for X3 absorption is $\approx7.1\times10^{19}$ m^{-3}. The absorption is a very sensitive function of the electron density. During X3 heating, plasma profiles of density and temperature change altering respectively the absorption plus refraction and the position of the absorption maximum. The launch mirror must be controlled, in real time, to accommodate this. A real time control system has been designed and implemented for this purpose. Feed-back control of the poloidal launch angle is achieved using an error signal obtained by measuring the plasma response (centrally viewing SXR camera) to a small sinusoidal oscillation imposed on the launch mirror. A controller based on this perturbation method has been implemented. Figure 3a shows a schematic of the controller and while Figure 3b shows the error, phase and plasma response signals to the mirror perturbation imposed on a linear ramp of the mirror poloidal angle. This experiment was done in an ‘open loop configuration. Closed loop have been started.

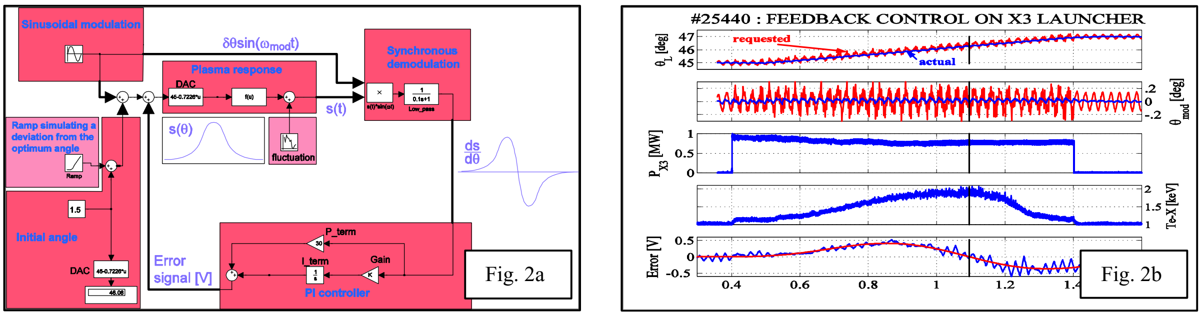


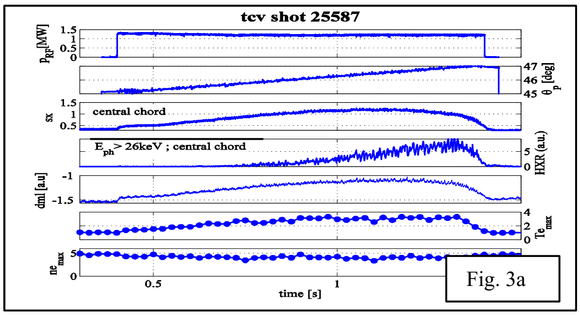
Fig. 2a

Fig. 2b

Figure 2a schematic diagram of the principle of operation of the real time mirror control system. A sinusoidal perturbation is applied to the mirror angle that causes a perturbation to the plasma response (central viewing SXR signal; TeX). This plasma perturbation is used to extract a phase signal that is zero when the mirror angle is at its optimal position. Figure 2b shows the plasma to a linear sweep of the mirror angle with the perturbation imposed upon it. The phase of the plasma response is zero at the optimal angle (peak of TeX).

FAST ELECTRON PHYSICS AND X3

X3 absorption can be higher than predicted by thermal plasma theory (at TCV the linear ray-tracing code TORAY-GA). Diamagnetic loop (DML) measurements [2] show that 100% X3 absorption can be achieved in cases where TORAY-GA predicts substantially less. Fast electrons play a significant role in X3 absorption. By sweeping the poloidal angle of the X3 launch mirror from the high field side (50^o) to the low field side (40^o) one, in effect, uses the relativistic line broadening to probe separately the response of fast electrons and thermal electrons. In this way it might be possible to use X3 absorption measurements as a tool for diagnosing fast electrons. Initial, proof of principle, experiments have been performed to test this idea. Using DML measurements (the *thermal + non-thermal* plasma response), electron temperature measurements from SXR signals (thermal plasma response) and ECE measurements (the fast electron response) it has been possible to separate the fast electron and thermal plasma responses. Experiments continue to examine the role of fast electrons in X3 absorption and to test the feasibility of using X3 absorption measurements to diagnose fast electrons.



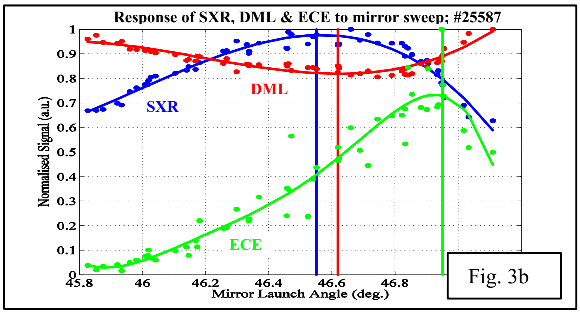
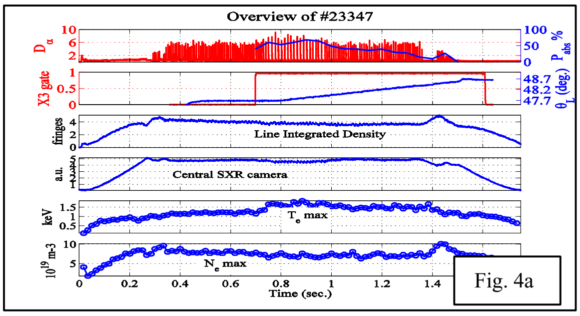


Figure 3a: overview of shot #25587 showing the X3 power gate (top), the poloidal angle of the launcher mirror, a central SXR signal, photon count (non-thermal response), the diamagnetic loop signal and the electron temperature and density. Figure 3b: the response of a central viewing SXR camera (thermal response), the diamagnetic loop (total plasma energy) and an ECE channel (non-thermal response). It is clear that as the mirror is swept from the high angle (fast-electrons) to low angle (thermal electrons) the thermal and non-thermal components can be excited separately. The total plasma response (DML) exhibits a peak shifted away from the thermal plasma peak showing, again, that fast electrons play an important role in X3 absorption.

H-MODE AND X3 HEATING

Efforts to heat H-mode have focussed on using X3 to heat quasi-stationary ELMy H-modes and to provoke the L- to H-mode transition using X3 heating. It is to be noted that the ELM type on TCV is still a subject for debate [3].



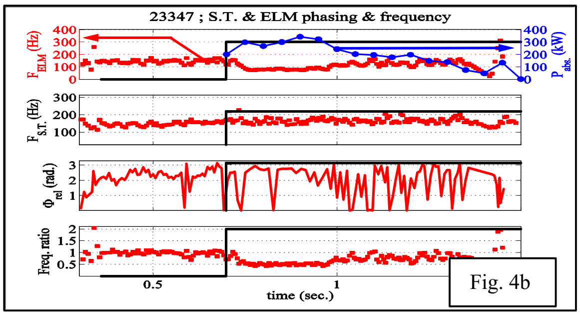


Figure 4a: Overview of shot #23347 showing the D$_\alpha$ with the coupled X3 power, the mirror launch angle and the power gate, the line integrated density, the maximum electron temperature and the maximum electron density. Figure 3b shows the ELM/SAWTOOTH frequency and phasing for #23347. Once the coupled power exceeds ≈200kW the ELM frequency drops to precisely one half the sawtooth frequency with a phase closed to but less than π; the ELMs *precede* the closest, in time, sawtooth. While the X3 coupled power <200kW and in the ohmic case the ELM frequency was very close to the sawtooth frequency. The ELMs precede the closest sawtooth in time.

ELMs and sawteeth on TCV are strongly coupled [4]. Experiments have been performed to examine the effect of core additional heating on this coupling. By heating an ELMy H-mode with X3 coupled power <400kW it was possible to maintain the ELMy H-mode. At coupled power <200kW the ELM/sawtooth relationship remained the same as in the ohmic case. However, at X3 coupled power >200kW the relationship changed. On a time scale similar to the energy confinement time, the ELM frequency dropped to one half the sawtooth frequency and the phase came close to locking (see Figure 3b). The ELMs still preceded the sawteeth. This observation is unexplained.

It has been possible to induce the L- to H-mode transition in ohmic L-mode discharges close to the transition threshold. These discharges have all transited directly into an ELM free H-

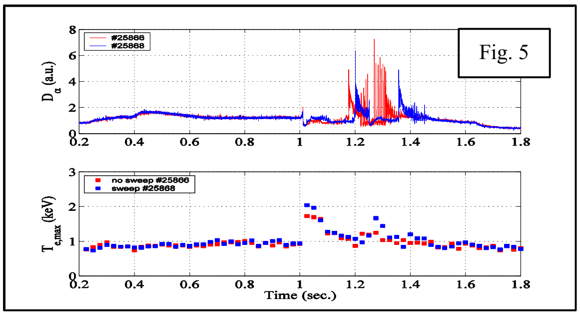


Fig. 5

mode with a consequent uncontrolled rise in electron density and coupled power loss due to refraction. Attempts have been made to combat the refraction by sweeping the launcher mirror angle. This has had some success in increasing the electron temperature and prolonging the H-mode phase. Figure 5 compares two discharges one without a mirror sweep (#25866; red) and the other with (#25868; blue). #25868 achieves higher electron temperature in the first H-mode phase (2keV compared to 1.8keV) and transits into a second ELM-free H-mode phase after the back transition. The mirror sweep reduced the effects of the density rise in the ELM free H-mode.

CONCLUSIONS

Experiments have begun to exploit the capabilities of the X3 additional heating system on TCV. It has proven necessary to incorporate a real time control system on the poloidal launch angle of the launch mirror. The real time controller is being commissioned. Experiments have been performed to examine the effect of moderate power X3 heating on the ELM/sawtooth phasing in TCV H-modes and it has proven possible to phase lock the ELMs and sawteeth at coupled X3 power >200kW. It has been possible to provoke the L- to H-mode transition using X3 but to control the H-mode thereafter and to maintain X3 power coupling has proven difficult due to the uncontrolled density rise in ELM free H-mode. Work continues to address this problem.

REFERENCES

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[3] L. Porte et al; ‘Third Harmonic X-mode Electron Cyclotron Resonance Heating on TCV using Top Launch’; Proceedings of the 19th IAEA Fusion Energy Conference, Lyon France 14th – 19th October 2002. Paper EX/P5-15

[4] Y. Martin et al; ‘Search for Determinism in ELM Time Series in TCV’; PPCF **44** (2002) A373-A382