SAWTEETH STABILIZATION AND ION TEMPERATURE ENHANCEMENT BY LOCALIZED ECRH IN FTU PLASMAS

S. Cirant, A. Airoldi, L. Bertalot*, G. Bracco*, A. Bruschi, P. Buratti*, A. Cenacchi†, B. Esposito*, G. Gervasini, G. Granucci, E. Lazzaro, S. Nowak, G. Ramponi, A. Simonetto, C. Sozzi, O. Tudisco*, M. Zerbini*, F. Alladio*, L. Acitelli*, B. Angelini*, M.L. Apicella*, G. Apruzzese*, E. Barbato*, A. Bertocchi*, G. Buceti*, A. Cardinali*, C. Centioli*, R. Cesario*, C. Cianfarani*, S. Ciattaglia*, V. Cocilovo*, F. Crisanti*, R. De Angelis*, F. De Marco*, D. Frigione*, L. Gabellieri*, G. Gatti*, C. Gourlan*, M. Grolli*, A. Imparato*, H. Kroegler*, M. Leigheb*, E. Giovannozzi*, G. Maddaluno*, G. Maffia*, M. Marinucci*, G. Mazziteli*, F. Mirizzi*, F.P. Orsitto*, D. Pacella*, L. Panaccione*, M. Panella*, V. Pericoli Ridolfini*, L. Pieroni*, S. Podda*, G.B. Righetti*, F. Romanelli*, F. Santini*, M. Sassi*, S.E. Segre*, S. Sternini*, A.A. Tuccillo*, V. Vitale* G. Vlad*, V. Zanza* and F. Zonca*

Istituto di Fisica del Plasma, Associazione EURATOM/ENEA/CNR sulla Fusione, via Cozzi 53, 20125 Milano, Italy

**Centro Ricerche Energia Associazione EURATOM/ENEA/CNR sulla Fusione, C.P.65, 00044 Frascati, Rome, Italy*

†*Centro Ricerche Energia, ENEA, Bologna, Italy*

1. Introduction

The study of energy transport in tokamaks is a main goal of ECRH at 140 Ghz, O-mode at fundamental resonance, on FTU, and the analysis of electron heat confinement has been extensively performed [this conference]. In addition, the ion heating capability due to the high cut-off density offers a chance to discriminate between the electron and ion loss channels, and sawteeth control permits investigation on the relation between MHD and transport.

2. ECRH at high electron density and ion heating

ECRH can be performed in FTU in a range of electron densities well above 10^{20} m^{-3}. The indirect response of ion temperature to localized ECRH is summarized in Fig. 1, where the ion temperature increase with on-axis heating with P_{ecrh} = 350 kW and the $T_{e,0}/T_{i,0}$ dependence with peak electron density are shown. The peak temperature $T_{i,0}$ is inferred from the neutron yield due to D-D reactions. Two factors limit the e-i heat exchange during ECRH: at low density ($n_{e,o}$ lower than ≈10^{20} m^{-3}), decoupling of electrons from ions is enhanced by the high T_e/T_i ratio achieved; at a density close to cut-off, a large heating power should be available to sustain an adequate e-i temperature difference.

The ion temperature is estimated from power-balance analysis. Given the measured electron temperature $T_e(r,t)$ and density $n_e(r,t)$, $T_i(r,t)$ is computed assuming a neoclassical Q_{e-i} power transfer and diffusive ion losses. Both terms can be adjusted using multiplicative anomaly factors, in order to obtain the best agreement with the experimental loop voltage, radiated power and neutron yield. Plasma current, electron density and temperature are the experimental values. All parameters are averaged over 10 ms, so that sawtooth effects are not taken into account. The rise time of the neutron emission is well reproduced if a purely neoclassical e-i heat exchange term is assumed; however, in order to match the measured neutron emission levels during both the ohmic and ECRH phases the ion diffusivity must be $3 \div 5$ times higher than neoclassical theory predictions (Fig. 2), as already observed in purely ohmic plasmas. The power transferred into the ions is still a small fraction of the total ECRH power (Fig. 3), and overall confinement is still dominated by losses through the electron channel (Fig. 4).

3. Sawteeth control

The effects of 350 kW of ECRH power on a sawtoothing FTU discharge at 350 kA, similar to the ones observed in other experiments [1], are shown in Fig. 3. In case of central heating, the sawtooth period is shorter than in the ohmic phase, the amplitude is larger and precursors with a period of the same order of the crash duration anticipate the reconnection. For off-axis ECRH ($r_{abs} \approx r_{inv} \approx 0.2$ a), the reconnection repetition rate is slower, the amplitude is the same as ohmic and no precursors are present.

Central heating peaks the current density profile and leads to a faster sawtoothing rate, while off-axis absorption can modify the central q profile by raising it above unity over at least a finite portion of the sawtooth unstable region, thereby removing the necessary condition for it. Transient inductive currents around the ECW absorption region may contribute to the process by enhancing the current density profile modification at switching ON of the ECRH power.

These experiments have been interpreted by using a diffusive transport code [2], which includes a Kadomtsev-like reconnection model, where temperature, density and safety factor profiles are instantaneously flattened inside the mixing region, through conservation of the helical flux (Fig. 4). The main experimental features (average temperature, s.t. amplitude, s.t, period and temporary suppression) are well reproduced with the only assumption of the q_0 value triggering the reconnection (0.92 in these cases).

The code, completed with the inclusion of ECCD calculated from a fully relativistic transport-quasilinear formalism [3], can be used to predict the ECRH power necessary for complete sawteeth stabilization (Fig. 7, 8).

4. Conclusions

ECRH can be performed on FTU in an unique density regime, characterized by effective e-i thermal exchange. The collisional e->i power transfer is as expected. Ion diffusivity can be 3÷5 times neoclassical estimates, as already observed in ohmic plasmas.

The main experimental features of the effect of ECRH on sawteeth can be reproduced by a diffusive transport code including Kadomtsev-like reconnections.

References

[1]- K. Hanada, T. Maehara, K. Makino, et al., Phys. Fluids B4, 3675 (1992)
[2]- A. Airoldi and G. Cenacchi, IFP Report FP 98/3, march 1998
[3]- Balescu, Mertens, Phys. FIuids B3, 1214 (1991)

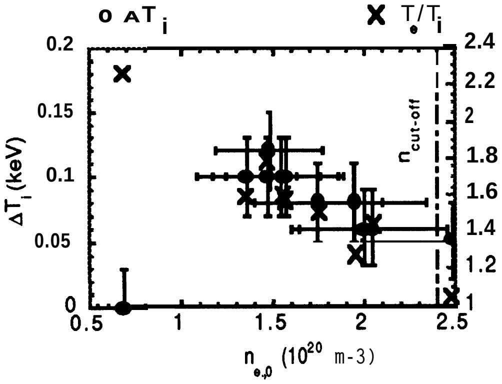

Fig.1 - Ion temperature increase as a function of the peak electron density. The ratio between peak electron and ion temperature during ECRH at 350 kW is also shown.

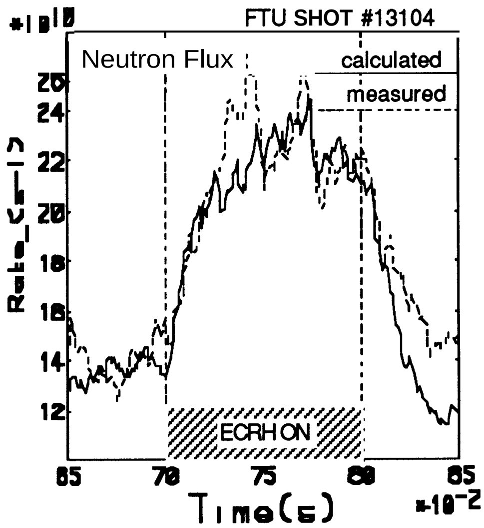

Fig.2 - Comparison between the neutron yield as measured by NE213 neutron detectors and the emission estimated by the transport code. The detector signal is averaged over 10 ms.

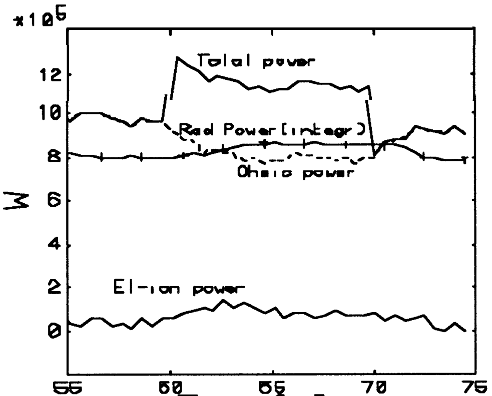

Fig.3 - The ECRH power transferred to the ions is still a small fraction of the power absorbed by the electrons.

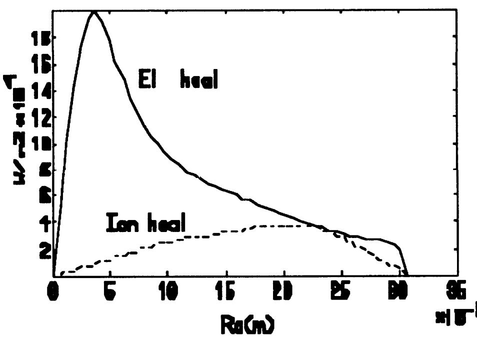

Fig 4 Electron heat conduction flux still dominates transport

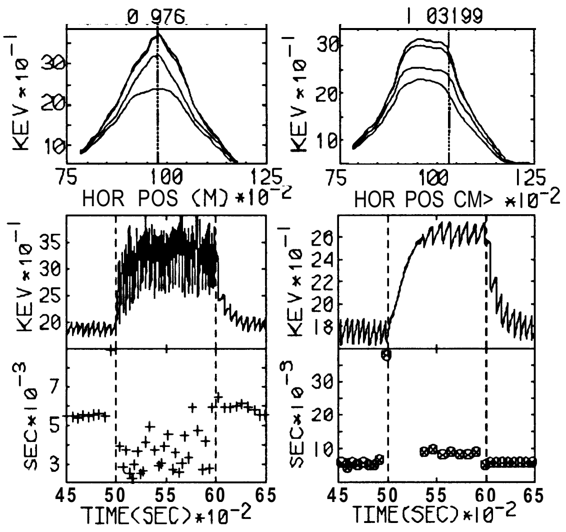

Fig.5 - Sawteeth evolution during on-axis (left column) and off-axis (right column; $\rho_{abs} \approx \rho_{inv}$ =0.2) ECRH.
Top: T_e profiles at different times during heating. Center: peak temperature vs. time. Bottom: s.t. period.

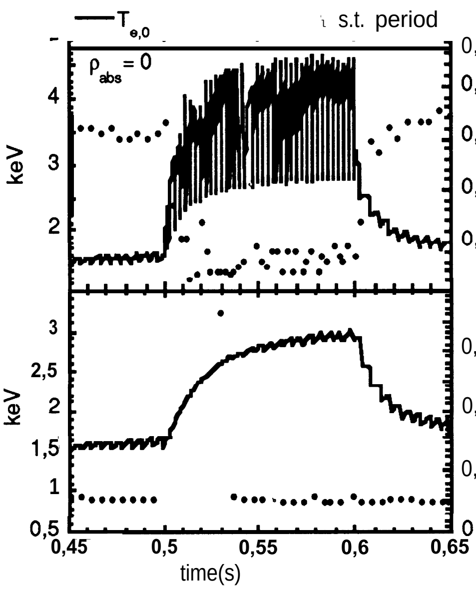

Fig.6 - Peak electron temperature and s.t. period calculated in a diffusive transport code with reconnections. The main experimental features are reproduced assuming reconnection at q_0=0.92

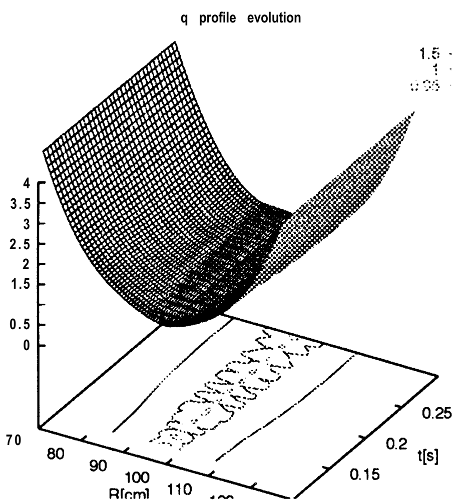

Fig.7 Calculated q-profile evolution with P_{ecrh} =0.8 MW, I_p=500 kA

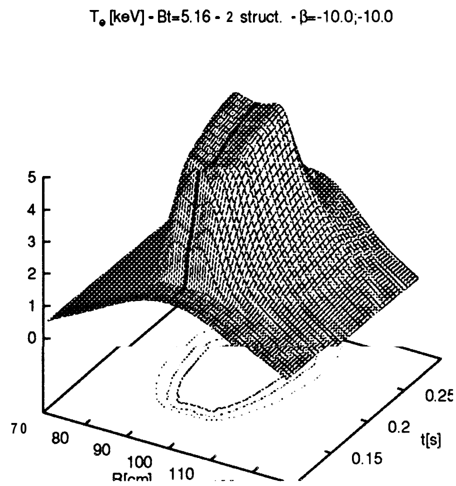

Fig.7 Calculated T_e-profile evolution with P_{ecrh}=0.8 MW,I_p=500 kA