Transiently improved confinement after off-axis ECRH in TEXTOR

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1. Introduction

It has been observed in TEXTOR (circular limiter tokamak, $R = 1.75$ m, $a = 0.46$ m) that, with a suitable choice of plasma parameters, the core electron temperature T_e stays constant for some time after the switch-off of off-axis ECRH. This delay can be as long as 35 ms, i.e. $\simeq 1.5$ energy confinement time. Similar observations were made earlier in the Russian T-10 tokamak [1, 2].

The fact that the central T_e stays constant for some time after ECRH switch-off while the off-axis T_e decreases at the same time, indicates that the electron thermal transport must be reduced. This is confirmed by calculations of the electron heat diffusion coefficient χ_e in steady state during ECRH and in the transient phase after switch-off.

2. Experiment

To analyze the effect, a systematic study was performed in TEXTOR, starting from ohmic target plasmas at standard plasma parameters (plasma current $I_p = 350$ kA, line averaged density $\langle n_e \rangle = 2.5 \cdot 10^{19} \text{m}^{-3}$). For the heating a single 140 GHz gyrotron was used, 800 kW, pulse duration up to 3 s, 2nd harmonic X-mode.
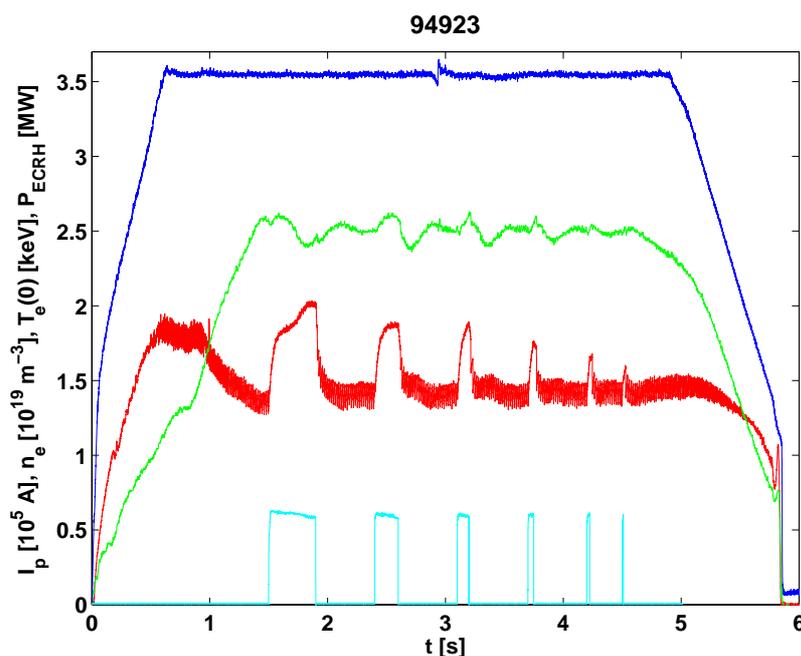

Figure 1: *Typical scenario of the experiments, Shown are I_p (blue), $\langle n_e \rangle$ (green), $T_e(0)$ (red) and ECRH power P_{ECRH} (cyan) for TEXTOR discharge 94923.*
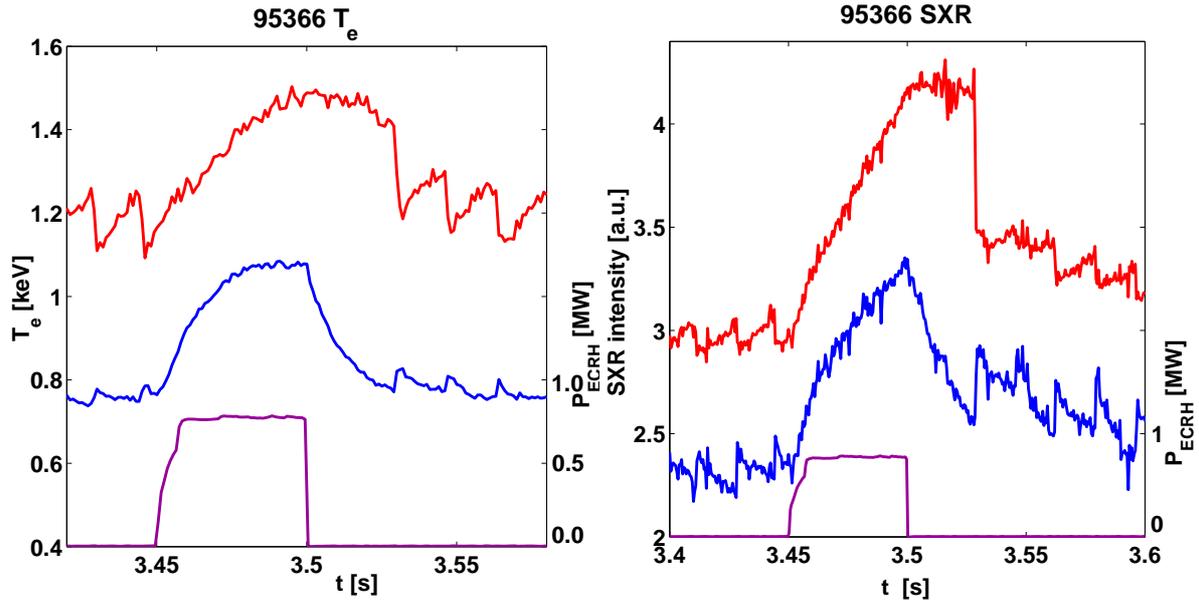
Figure 2: *Typical behaviour after switch-off of off-axis ECRH. Left: $T_e(t)$ from ECE from a central channel (red) and a channel just outside ρ_{dep} (blue). Right: SXR time traces from a central chord (red) and a chord just outside ρ_{dep} (blue). The ECRH power is given in violet.*

Within one discharge, 6 ECRH pulses were applied, with pulse length 400, 200, 100, 50, 25, and 10 ms, respectively. The magnetic field B_t was varied in small steps between shots, to vary the power deposition location of ECRH (ρ_{dep}). The scenario is given in Fig.1. Then Fig.2 shows the typical time evolution after switch-off of off-axis ECRH, as observed on the ECE (left) and SXR (right) channels. The T_e profile evolution after ECRH switch-off is shown in Fig.3.

Whether or not the delay of central T_e decay occurs depends critically both on the precise value of ρ_{dep}, which should be close to the sawtooth inversion radius, and on length and power of the ECRH pulse (τ_{ECRH}, P_{ECRH}). E.g., for some values of ρ_{dep} a strong effect is seen after a relatively short ECRH pulse (50 ms or less, i.e. much less than the current diffusion time), whereas it is not seen when the ECRH pulse is long enough to reach full current redistribution; see Fig.4 for an example of this.

3. Modelling and Discussion

First it has been checked that the observed behaviour can only be explained by assuming a rapid change of χ_e after ECRH switch-off: Fig.5 shows both the measured (full lines) and the calculated time evolution (dashed lines) of $T_e(0)$ (red) and T_e just outside ρ_{dep} (blue). The calculations use the experimental profiles of T_i and n_e and a χ_e, constant in time, which reproduces the observed T_e profile at the end of the ECRH pulse. The calculated $T_e(0)$ starts to drop almost immediately; also the decay just outside ρ_{dep} is too fast. Then a full calculation of the dynamic power balance has been performed with the ASTRA and COBRA codes [3, 4]. They show (Fig.6) that indeed an almost instantaneous drop of χ_e is needed to explain the observations.

The fact that the delay of central T_e decay critically depends on ρ_{dep} and on τ_{ECRH} and P_{ECRH} points to the role of the safety factor profile $q(r)$. It is believed [1, 2] that a region of low magnetic shear near a low order rational surface is essential to produce
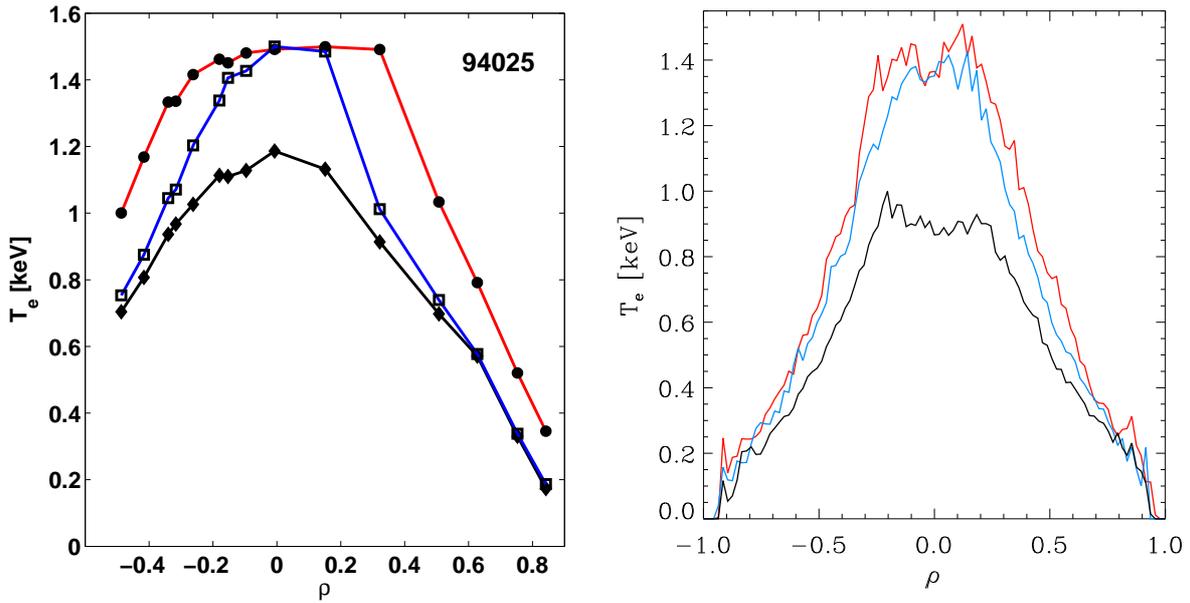
Figure 3: T_e *profile evolution after ECRH switch off, as measured by ECE (left panel) and Thomson scattering (right panel). The profiles in red were measured during steady state ECRH (red), those in blue during the decay 20 ms (left) and 10 ms (right) after ECRH switch off, and those in black during the ohmic steady state.*

the effect by inducing the formation of an internal transport barrier. Calculations of the current density evolution have shown that indeed transiently a low shear region near ρ_{dep} can be formed after ECRH switch-off. The q value in this low shear region strongly depends on ρ_{dep} and τ_{ECRH}.

In near future it is planned to further probe the transient phase of confinement improvement by applying high power NBI immediately after ECRH switch-off. Moreover, a Motional Stark Effect (MSE) diagnostic has become available recently on TEXTOR. A few discharges were performed with additional low power NBI, needed to operate the the MSE diagnostic; currently the MSE data are analyzed, in order to extract information on possible changes in the q profile during ECRH and after ECRH switch-off.

Conclusion

A transient phase of improved confinement of up to $\simeq 1.5\tau_E$ after off-axis ECRH switch-off has been discovered in TEXTOR. The improvement, found earlier in T-10, is attributed to the formation of a low magnetic shear region.

References

[1] Razumova K.A. et al, *30th EPS Conf. (St.Petersburg)* Vol 27A (Geneva, EPS) CD-Rom Paper P-3.118
[2] Razumova K.A. et al, accepted for publication in *Nucl. Fusion* (2004)
[3] Pereverzev G.V. and Yushmanov P.N., *ASTRA: Automated System for Transport Analysis in a Tokamak.* Max-Planck Institute Report, IPP 5/98
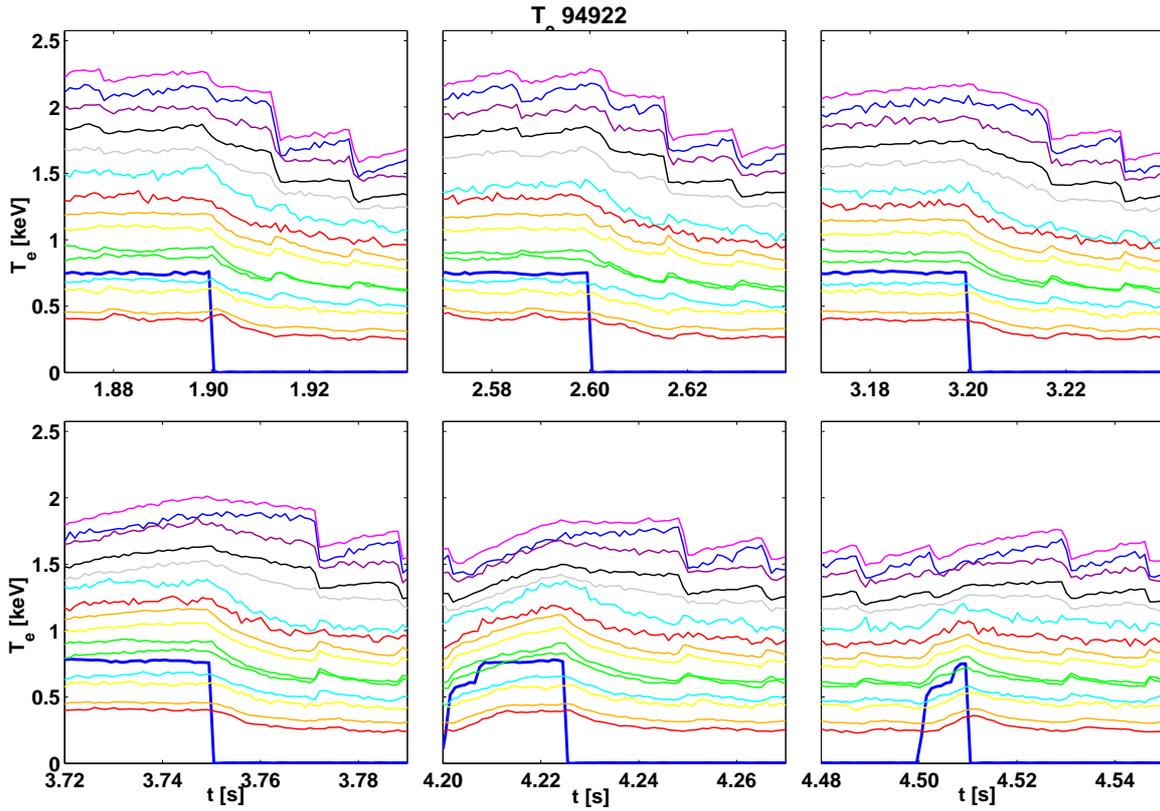[4] Andreev V.F. et al, *Plasma Phys. Contr. Fusion* **46** (2004) 319

Figure 4: *ECE T_e time traces after switch-off of ECRH for TEXTOR discharge 94922. The 6 panels show the time windows around the switch-off times of the 6 ECRH pulses, which had lengths of 400, 200, 100, 50, 25 and 10 ms, respectively. The delay of central T_e decay is only seen after the shorter ECRH pulses.*
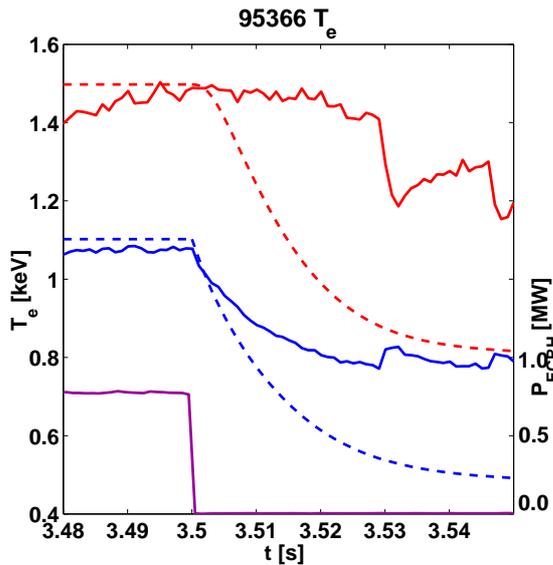

Figure 5: *Calculated T_e evolution after ECRH switch-off assuming that electron thermal transport is not modified (see text).*
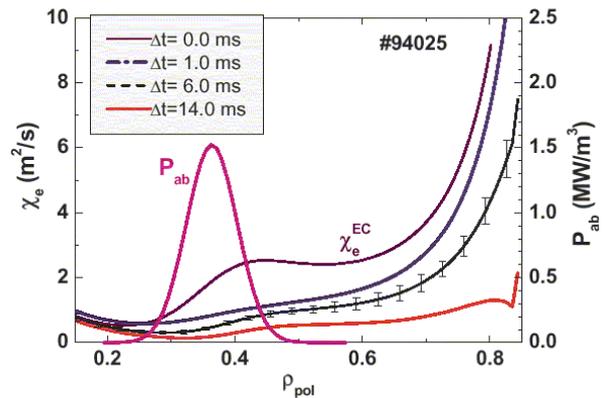

Figure 6: *COBRA calculation of χ_e during ECRH and at various times after ECRH switch off.*