First results of ECRH on TEXTOR: filaments, barriers, and RI-mode

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**Partners in the Trilateral Euregio Cluster (TEC)*

Introduction

End 1998 FOM-Rijnhuizen ended the operation of RTP in order to concentrate its tokamak physics research on the central device of the Trilateral Euregio Cluster, TEXTOR-94 at Forschungszentrum Jülich. The contribution of FOM to the TEC-collaboration is in line with its interest in non-linear electron dynamics and turbulent electron transport. In the one-and-half year since the end of RTP several new systems were built up on TEXTOR of which the first results can now be reported: an ECRH/ECCD system and several diagnostics mainly supplying information on the electron behaviour.

An important aim of the initial experiments has been the verification of the striking results obtained in RTP: self-organized structures in low shear areas in the form of high temperature filaments and the existence of very localized electron transport barriers near rational q-surfaces. These RTP results were sometimes received with some reserve on their general validity since the small dimensions of RTP (R=0.72 m; a=0.164 m) made the ECRH power-density extremely high (volume averaged 1 MW/m^3). The electron-ion equilibration time was longer than the energy confinement time so that the ion-transport didn't play an important role. TEXTOR-94 is about a factor 25 larger in volume (R=1.8 m; a=0.48 m). Due to that the equilibration time between electrons and ions is about equal to the energy confinement time.

Experimental Set-up

ECRH: A 400 kW, 110 GHz, 200 ms gyrotron has been installed delivering the power in X-mode at 2 ω_{ce} via a quasi-optical transmission line into a LFS launcher. Tiltable mirrors allow variable poloidal and toroidal launching angles: full coverage of the plasma cross-section and beams tangential to the major radius in co- and counter-direction. The beam can be focussed / defocussed and the ellipticity of the polarization varied.

Diagnostics: six new systems are operational now, only a few will be discussed in this paper. First of all the high spatial resolution Thomson scattering system [1]: a vertical laser chord is observed via a fiber optics image relay system with 8 mm spatial resolution on 115 points along the full plasma diameter. The laser in combination with the CCD camera recorder allows double pulses with a variable time delay between 50 and 500 microseconds.

ECE Imaging: the EC-emission of a vertical array of sample volumes is imaged quasi optically by lenses onto a detector array. All 16 channels are connected to the same tuneable local

oscillator. Selecting the proper frequency causes the vertical observation chord to coincide with the Thomson laser beam allowing calibration on Thomson scattering. By varying the LO frequency the vertical chord of observation is scanned along the major radius. The spatial resolution is about 1-1.5 cm in both the poloidal and radial direction.
Conventional ECE: single receiver antenna connected to a multichannel heterodyne detection system. In the past this was the only source of information on the electron temperature of TEXTOR. In fig.1a a comparison is made between the Thomson scattering profile (red) and this old system. As the latter gives the profile along the major radius the observation points are mapped on the vertical Thomson chord following the flux-surfaces in clockwise direction (dark blue) and anti-clockwise (light blue).

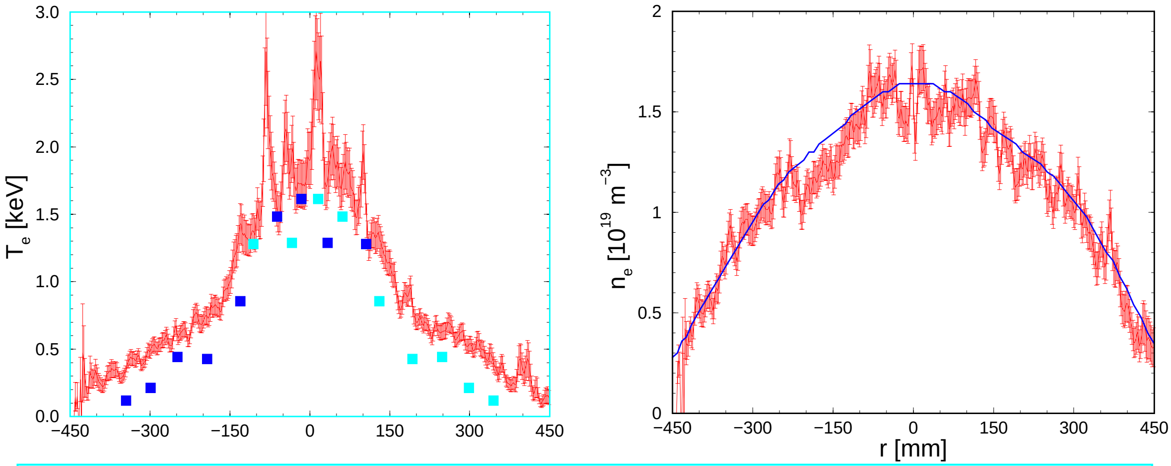

Fig.1 left: *TS T_e -profile revealing the small-scale filamentary structure of $T_e(r)$. In blue the result of the old ECE system. Central ECRH with 250 kW of a q_a = 6.4 discharge*
Fig.1 right: *The TS density of the same pulse is scaled to the peak of the profile obtained from Abel inversion of the multichannel interferometry.data.*

Filamentation of the central core

Results from high resolution Thomson scattering (TS) confirm (Fig.1) the filamentation of the T_e -profile during central ECRH (250 kW) as observed earlier on RTP at the same q_a –value.

Also the results of ECE Imaging indicate the highly structured nature of the central temperature profile although the spatial resolution is somewhat less. The diameter of the filaments observed in TEXTOR is much larger than in RTP indicating proportionality with minor radius. If one adopts the explanation of the filaments as being 'hot snakes' [2] or 'positive islands' (terminology of S.Mirnov [3]), i.e. slender tori floating inside the q=1 surface, it is not difficult to explain that the filaments in both machines show the same improved heat-diffusivity of about 5.10^{-2} m^2/s. Although the heatflux crossing the surfaces of the filaments in TEXTOR is a factor 4 lower than in RTP, this is off-set by a factor 3 lower temperature gradient inside the filament combined with 25% lower density. Altogether this leads to a similar temperature excursion in the filaments of 1.5 keV in both machines.

Transport barriers near integer and other rational q-values

In RTP it has been shown [4] that in case the plasma transport is fully dominated by electron transport the effective heat diffusivity is extremely discontinuous. Layers of very low diffusivity near, but not at, rational q-surfaces act as thermal barriers. In between these layers the diffusivity is very high and magnetic islands were observed. An empirical heat diffusivity distribution solely determined by the local q-value has been derived. The model could explain a wide variety of steady state as well as strongly dynamic situations. Question is if this empirical RTP-model could be equally valid for other tokamaks. Therefore the same model has been applied to TEXTOR-plasmas with central deposition of 340 kW ECRH in first instance without changing the $\chi(q)$- distribution. The result is striking, see Fig.2. Not only the radius of the q=1 radius is predicted correctly also the absolute temperature value. Although the heat-flux is not large enough to raise the individual barriers outside q=1 above the statistical error in the Thomson measurement, nevertheless is the collective action of barriers with q>1 describing accurately the overall slope of the profile towards the edge. However, the actual power deposited in the plasma has been 250 and not 340 kW. In general this type of plasmas follow L-mode scaling in RTP as well as in TEXTOR. One should therefore adjust the overall level of $\chi(q)$ with a scaling factor following L-mode scaling from RTP to TEXTOR. This means that one should take $\chi(q,\mathrm{TEXTOR}) = 0.83\ \chi(q,\mathrm{RTP})$. Redoing the calculation for the actual 250 kW and with this reduced diffusivity gives again the same profile indiscernible from fig.2.

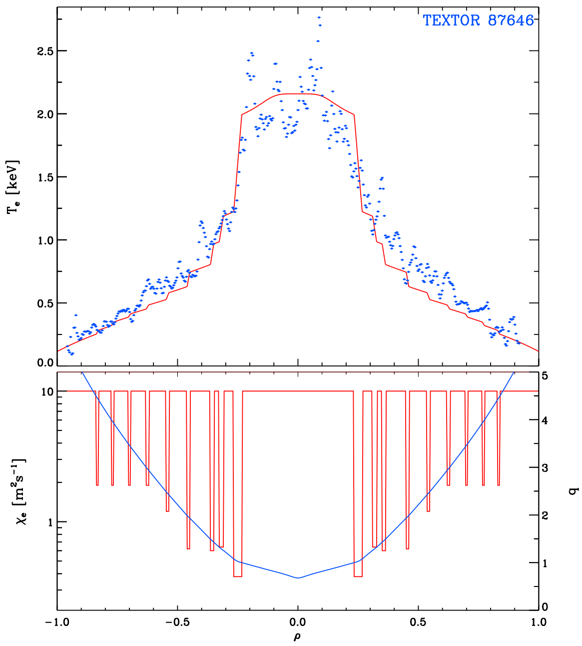

Fig.2 *Simulated (red) and measured (blue) Te-profile for 340 kW of ECH using layered $\chi(q)$ profile from [4].*

Obviously the existence of these barriers calls for exploitation with low or negative central shear at q>1. This leads to record T_e-values obtained during the current-ramp, see fig.3. The strong barriers shown are probably q=3, although a proof of that has to wait for MSE-measurements later this year. Interesting is that off-axis heating just inside the barrier leads to hollow profiles. These profiles are vulnerable for inward collapses. With central deposition the plasma is more stable. Simultaneous heating with NBI gives robust current-ramp scenarios.

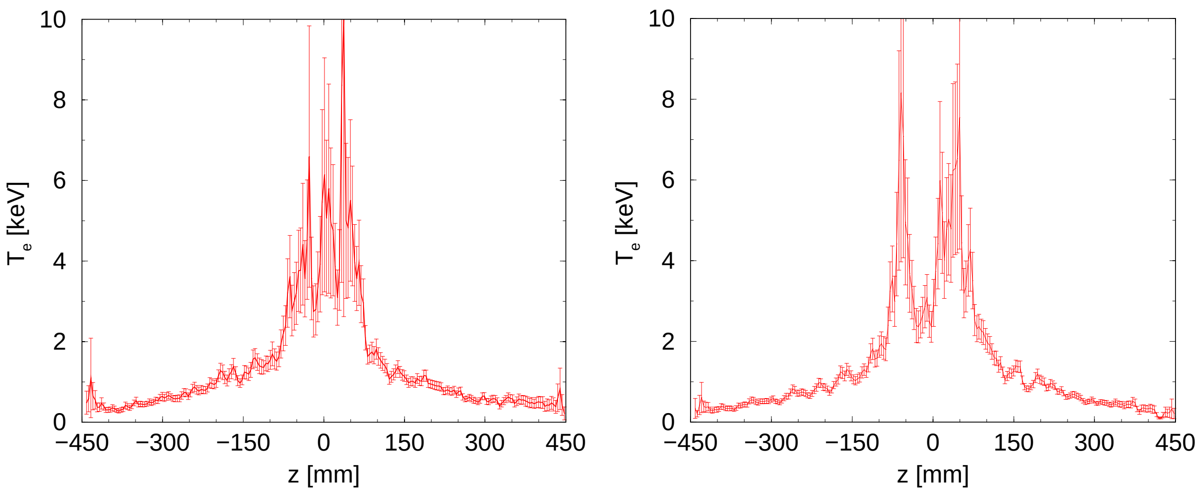

Fig.3 *Te-profiles from Thomson Scattering obtained with ECH during the current ramp phase. Left: discharge # 87655 central ECH. Right: discharge # 87654 slightly off-axis ECH*

ECRH of RI-mode plasmas

T_e -profiles of high performance RI-mode discharges [5] have been obtained close to the beta limit. Results show record values of central electron pressure up to 0.6 atmosphere with almost equal pressure for the ions.

Central ECRH with 250 kW, 200 ms in a RI-mode discharge with 750 kW of NBI and 800 kW of ICRH gives an increase of diamagnetic energy in proportion to the additional power (Fig.4). It will be interesting to see in future experiments if this lack of power degradation with ECRH in RI-mode still holds when the EC-power can be raised to 1 MW. The T_e -profile shows an increase in T_e of 400 eV, consistent with the increase in diamagnetic energy at this high density of 6.10^{19} m^{-3}. No measurable increase of T_i is observed (accuracy about 200 eV).

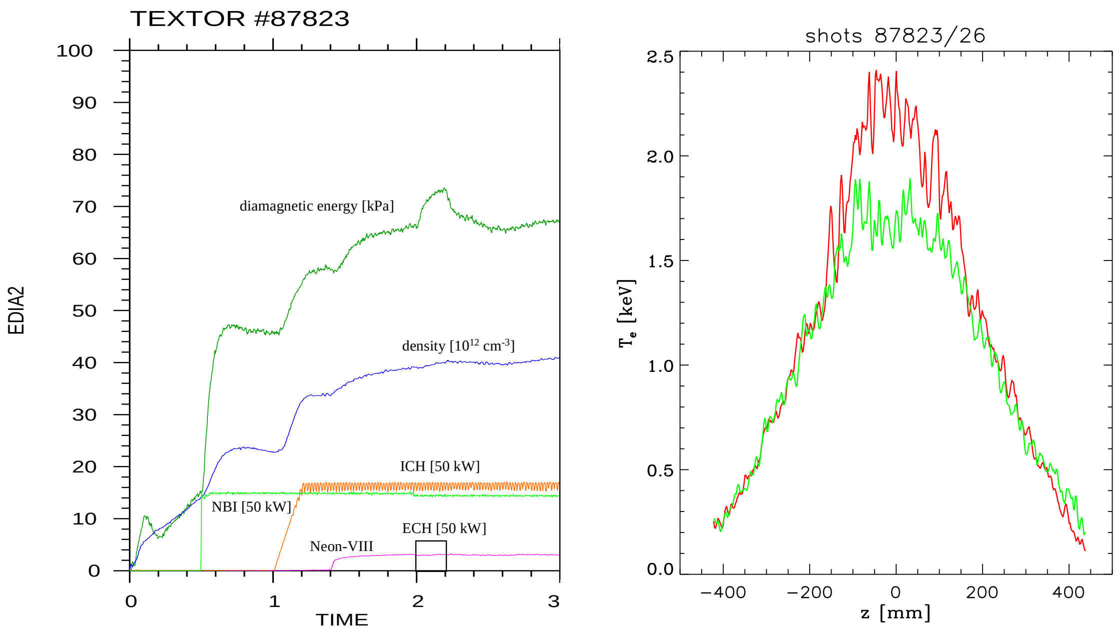

Fig.4 *EC heated RI-mode discharges. L- to RI-mode transition at t=1.4 after beginning of Neon injection. Time evolution (left) and Te profiles (right) in a discharge with (red) and without (green) ECH.*

Conclusions

1. Filamentation of the central T_e during central ECRH confirms the earlier results of RTP.
2. The empirical layered electron heat diffusivity model of RTP with barriers near rational q-surfaces is confirmed in TEXTOR.
3. Strong transport barriers at q>1 appear in the NCS phase during current ramp.
4. ECH during RI-mode leads to increase of energy content without confinement degradation.

Acknowledgements

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