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ECH power dependence of electron heat diffusion in ECH plasmas of the TJ-II stellarator

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Introduction

TJ-II discharges with electron cyclotron resonance heating (ECRH) and boronised wall conditions show a ECRH power dependence of the thermal energy confinement time following the power law, $\tau_E \sim Q_{ECRH}^{-0.6}$ [1]. This dependence, the so-called power degradation, is a robust feature observed in both stellarator and tokamak plasmas. However, the inherent physics of power degradation is not understood. A common approach to elucidate on the problem is to search for local plasma parameter dependencies of the thermal diffusivity consistent with power degradation. In this work the power degradation is investigated on the basis of the local power balance and the calculated radial electric field.

Experimental data

Data have been taken from steady state discharges with on-axis heating with two gyrotrons where the ECRH power was varied between 0.2 and 0.6 MW. We have used measurements of the plasma electron temperature, T_e, (Thomson Scattering TS) and density profiles, n_e, (TS) in stationary conditions in the vicinity of the TS time. In the case of ion temperature, T_i, we have used data from charge exchange diagnostic assuming that the T_i profiles in TJ-II ECRH shots are flat [2]. The values of the line-averaged density are in the range 0.6-0.7 10^{19} m^{-3}. All the analysis was performed with ASTRA shell using TJ-II vacuum flux surface geometry, similar to Ref. [3].

Neoclassical transport model

The radial electric field is obtained by solving the ambipolar equation from neoclasical fluxes of electrons and main ions. The neoclassical model used is from Ref. [4]. This model calculates the axisymmetric tokamak-like part [5] and an asymmetric helical part [6], and it has been previously checked for LHD plasmas in Ref. [7] and for TJ-II plasmas in Ref. [4] by comparing it with MonteCarlo calculations [8]. The expression for the radial asymmetric neoclassical flux associated with helical-ripple trapped particles Γ_j^{na} and heat flux Q_j^{na} of electrons ($j = e$) and ions ($j = i$) is given in Ref. [4]. The geometrical factors ε_h and ε_t that appear in the neoclassical equations are obtained by means of the equilibrium solver VMEC, with the pertinent corrections in order to take an effective ripple that somehow accounts for the complexity of the TJ-II magnetic configuration. The ambipolar equation is solved for every radial point in the plasma and the electric field obtained is plotted for the different ECRH power in figure 1.f.

Results and conclusions

The data lead to dependencies of the form $\chi_e \sim Q_{ECRH}^{0.6}$ and $\chi_e \sim T_e^{1.40}$ around $\rho = r/a = 2/3$, confirming and extending previous results [3]. Previous scalings in other stellarators show similar results i.e., $\chi_e \sim Q_{ECRH}^{0.58}$ and $\chi_e \sim T_e^{1.38}$ in the LHD [9] , $\chi_e \sim Q_{ECRH}^{0.76}$ in the W7-AS semi-local scaling [10], and $\chi_e \sim T_e^{1.52}$ Heliotron-E scaling [11] near to the position $r/a = 2/3$. The figures 1.a and 1.b shows that in the core and edge regions χ_e behaves differently. There are three confinement regions in ρ with different ECRH power dependence with χ_e and the local parameter T_e (see figure 1.e). The diffusivities seem to be less affected by Q_{ECRH} between $0.2 \leq \rho \leq 0.4$, probably due to a strong electric field (electron root), as figure 1.f shows. In $\rho \approx 0.5$ a nearly flat χ_e profile is observed up to $Q_{ECRH} \approx 350$ kW, which evolves into a peaked profile as the maximum heating $Q_{ECRH} \approx 600$ kW is approached, a feature known from previous scans in TJ-II stellarator [3].

The calculated neoclassical radial electric field agrees in general with previous calculations [4] and measurements. A comparison between the electric field calculated and obtained by radial plasma potential profiles has been carried out for TJ-II shot 17487. Radial plasma potential profiles have been obtained in TJ-II by the HIBP diagnostic [12]. The plasma potential φ is measured directly by the 125-keV Cs^+ HIBP [12] with temporal (10 μs) and spatial (1 cm) resolution in the radial range $-1 < \rho < 1$. There is a strong positive electric field at the center and a small negative one at the edge. The comparisson between the figures 1.e and 1.f shows that χ_e decreases slowly near $\rho \approx 0.3$, while the electric field strength increases sharply with the ECRH power. In contrast, the opposite behaviour is found near $\rho \approx 0.5$. In order to quantify this change, the electric field shear has been plotted in figure 1.g. The maximum value, $|dE_r/dr| \approx 30$ Vcm^{-2}, is given at $\rho = 0.3$ and $dE_r/dr \approx 0$ Vcm^{-2} near $\rho = 0.5$, thus where $dE_r/dr \approx 0$ Vcm^{-2} the electron heat diffusivity increases, and decreases where $|dE_r/dr| > 15$ Vcm^{-2}.

A comparison between the corresponding neoclassical transport coefficients and the power balance results is presented in figure 1.h. This figure shows the percentage of deviation from neoclassical electron heat diffusivity in the interval $0.2 \leq \rho \leq 0.8$ for the different ECRH powers. The conclusion is that neoclassical transport is much higher and important in the center than in the edge and that its relative importance increases with the ECRH power increase. The neoclassical heat diffusivity is of the the order of the experimental one in the plasma core for higher ECRH power values. For low power values, the region where they are comparable is reduced. At the boundary electron heat transport is clearly anomalous, i.e. it exceeds by far the neoclassical predictions.

References

[1] E. Ascasíbar *et al.*, Nucl. Fusion **45**, 276 (2005).

[2] J. M. Fontdecaba *et al.*, Fusion Sci. Tech. **46**, 271 (2004).

[3] V. I. Vargas *et al.*, Nucl. Fusion **47**, 1367 (2007).

[4] J. García *et al.*, Phys. Plasmas **14**, 102511 (2007).

[5] K. C. Shaing and J. D. Callen, Phys. Fluids **26**, 3315 (1983).

[6] E. C. Crume *et al.*, Phys. Fluids **31**, 11 (1988).

[7] S. Toda and K. Itoh, Plasma Phys. Controlled Fusion **44**, 325 (2002).

[8] V. Tribaldos *et al.*, Phys. Plasmas **8**, 1229 (2001).

[9] K. Yamazaki and T. Amano, Nucl. Fusion **32**, 4 (1992).

[10] H. Ringler *et al.*, Plasma Phys. Control. Fusion **32**, 933 (1990).

[11] F. Sano, Y. Takeiri, K. Hanataki, Nucl. Fusion **30**, 81 (1990).

[12] I. S. Bondarenko *et al.*, Czech. J. Phys. **50**, 1397 (2000).

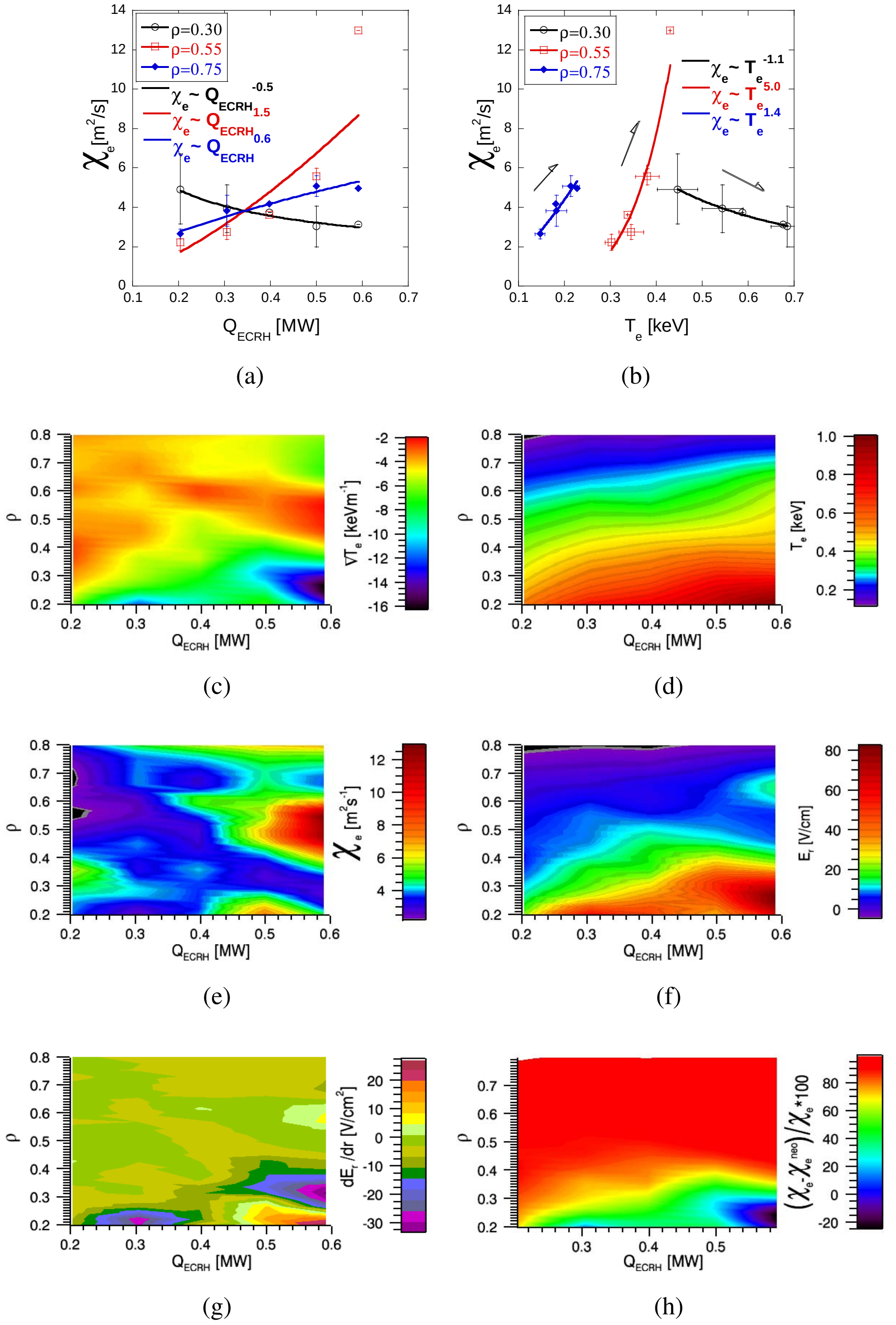

Figure 1: Experimental values of χ_e at $\rho = 0.30$, $\rho = 0.55$ and $\rho = 0.75$ as a function of: (a) ECRH power and (b) electron temperature. Contour maps of: (c) electron temperature gradient, (d) electron temperature, (e) electron heat diffusivity, (f) calculated radial electric field, (g) electric field shear and (h) percentage of deviation from neoclassical electron heat diffusivity; in the radial interval $0.2 \le \rho \le 0.8$ for the different ECRH powers.