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Dependencies of electron heat diffusion in TJ-II ECRH plasmas

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Introduction

TJ-II discharges under electron cyclotron resonance heating and boronised wall have shown a dependence of the thermal energy confinement time following the power law $\tau_E \sim \bar{n}^{-1} \iota^{0.4} P_{ECH}^{-0.5}$ [1]. In this work we perform interpretative transport on three series of discharges belonging to the corresponding scans (density, rotational transform and electron cyclotron resonance heating power) seeking to gain information on the plasma regions where the changes in electron heat diffusion take place. A simple formula to obtain the thermal conductivity, χ_e, assuming pure diffusion and negligible convective heat fluxes was used in a set of 204 steady state discharges and similar wall conditions (boronized wall). All the analysis was performed with the ASTRA shell after imposing TJ-II flux surface averages of the metrics to estimate gradients and volume integrals properly. Finally, the data dispersion was obtained statistically as there was a significant number of repetitions per experiment.

Density, rotational transform and power scans

We have performed interpretative transport analysis on sets of 74 discharges (density scan), 96 discharges (rotational transform scan); and 34 discharges (power scan). Here we are interested mainly in diffusive heat transport, a reason why our region of interest excludes the proximity of the magnetic axis (where the ECRH deposition drives strong pump out losses) and the edge (where magnetic field ripple losses dominate transport). Experimental information consists of the profiles of electron density n_e and temperature T_e (*Thomson Scattering* TS); ion temperature T_i (Charge exchange), and total radiation density P_{rad} (bolometry). Line density integrals were performed to ensure that the integral values for the reconstructed density profiles match the experimental line densities measured with interferometry techniques. Ion density is obtained considering a homogeneous efective charge $Z_{eff} = 1.3$. In the case of T_i, charge exchange data were only available for a few discharges. It is, however, known that T_i profiles in TJ-II ECRH shots are flat with values close to 90 eV [2]. We have then used a same 90 eV flat profile dropping to 12 eV at the boundary for all discharges. 12 discharges in the density scan and 9 discharges in the rotational transform scan have data on total radiation profile obtained from bolometer chords. All the discharges analyzed have the same deposited heating power (Q_{ECH} = 240 kW of ECRH without significant current drive) and

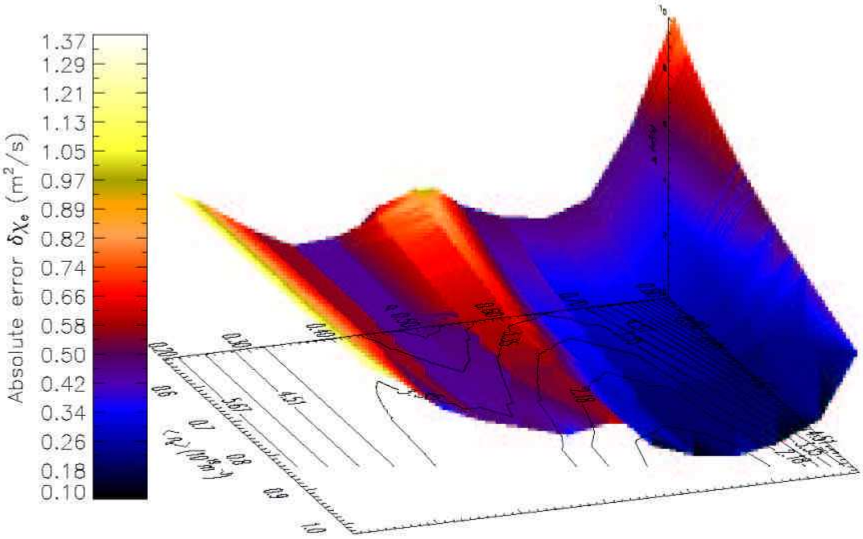

Figure 1: Thermal diffusivity profiles (0.2<ρ<0.8) as a function of line average density obtained from a power law fit to a set of 74 discharges for selected radii. The standard error (from the fitting parameters) is colour-coded (see scale to the left).

we have assumed a centered gaussian profile of width 0.2 in normalized minor radius. At this respect, it has been checked that the electron cyclotron absorption signals are similar for all discharges.

Results and conclusions

Typical density, profiles n_e of TJ-II ECRH plasmas are hollow, the density gradient region starting at normalised radius $\rho \approx 0.6$. Discharges with densities between 0.5 $10^{19}m^{-3}$ and 0.9 $10^{19}m^{-3}$ were used for the density scan, for which the rotational transform has a value of 1.65 at the plasma edge and the plasma volume is fixed: 1.098 m^3. The formula for the electron heat diffusivity used is $\chi_e(\rho) = Q_e^T(\rho)/n_e(\rho)\nabla T_e(\rho)G(\rho)$, where $Q_e^T = \int_0^\rho P_e^T dV$; $P_e^T = P_{ECH} - P_{ei} - P_{rad}$ and $G(\rho) = \partial V/\partial\rho\left\langle(\nabla\rho)^2\right\rangle$. The errors in χ_e, were obtained for selected minor radii in different ways. A power law fit was suited for the density scan, whereby the errors were obtained; but as a general rule, discharges grouped by vacuum rotational transform, small density ranges or heating power were used to obtain the dispersion in χ_e as standard deviation. The results suggest that a description of electron heat transport via the diffusive prescription may be meaningful in the region $0.3 < \rho < 0.8$ approximately, since the high statistical dispersion in the core (< 0.3) and edge (> 0.8) regions, together with their probably unrealistically high values of χ_e, make them not suited for this kind of analysis. Fig. 1 shows the thermal diffusivity profiles obtained in the density scan. It has been

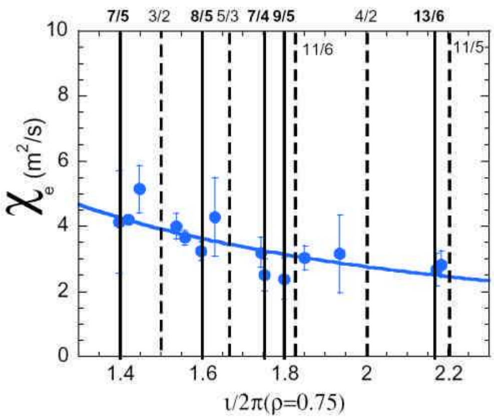

Figure 2: Thermal diffusivity at ρ=0.75 as a function of the local rotational transform. A power-law fit is shown, although the lowest values of χ_e seem to correlate with the presence of a low order rational of the rotational transform. The bars represent standard deviation.

obtained after performing power-law fits to the data for selected radii. Inside ρ=0.4 there is no significant change of χ_e with density in the range studied ($0.4 \approx \langle n_e \rangle (10^{19} m^{-3}) \approx 1.0$), while in 0.5<ρ<0.8 approximately, χ_e decreases with density. A general result in the meaningful region is that χ_e mimics the density profile. In particular, the density scan indicates that χ_e is closer in shape to n_e the larger the line density. This translates into a deepening of χ_e in the density gradient region for larger line densities, which is consistent with the favourable scaling of τ_E with density. The shoulder found in n due to its hollowness is also generally displayed by χ_e in the same position, although the standard deviation of χ_e is larger here. These radii (≈ 0.5), being far enough from the heat deposition zone, are thus coincident with a flattening of temperature profiles. Seeking to gain information on the source of variation of χ_e in the (ρ≈0.5) region, the time evolution of the electron temperature gradient (∇T_e) was studied based upon electron cyclotron emission diagnostic (T_e^{ECE}) for 64 discharges belonging to the density scan. With constant n_e, the T_e^{ECE} signal was used for ±10 ms around the time in which the firing of the TS diagnostic occurs. The result is that the time variation of ∇T_e in this region (ρ≈0.5) cannot explain the statistical dispersion among discharges.

The magnetic configuration, or rotational transform (ι) scan has revealed that a global scaling may lose significance because the presence of low order rationals, at least in the region of steepest density gradient (roughly the outer half of the minor radius), affects χ_e. This is illustrated in Fig. 2, where we plot χ_e at ρ=0.75 as a function of the ι value at the same location. The values of χ_e when a low

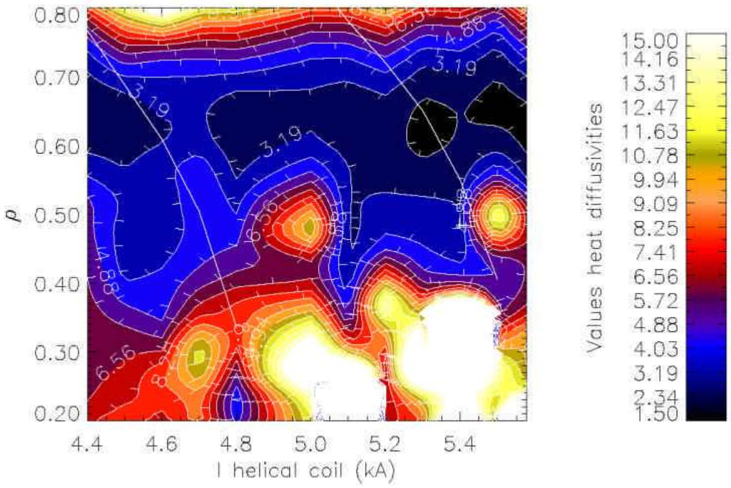

Figure 3: Thermal diffusivity profiles (0.2<ρ<0.8) as a function of helical coil current obtained from configuration-averaged values a set of 43 discharges. The vacuum rational surfaces ι =8/5 and 5/3 are shown by the thick lines. χ_e values greater or equal to 15 m^2/s are displayed in white.

order rational (poloidal number $2 < m \leq 6$) of ι is present locally seem to be smaller for the corresponding range, although it is apparent a general tendency of χ_e to decrease with increasing ι, as indicated by the power-law fit. This effect is clearer in the radial positions that correspond to the density gradient region, roughly 0.6 < ρ < 0.8, suggesting a general beneficial effect of the corresponding change in magnetic structure. Fig. 3 shows the configuration-averaged for the thermal diffusivity profiles obtained in the ι scan, where the ι = 8/5 and 5/3 are moved through the plasma. Just inside the low order rational surfaces (thick lines). Fig. 3 also suggests that a furrow in the χ_e map moves following the ι = 8/5 and 5/3 lines towards the plasma core until a so called e-ITB [3] shows up for helical coil currents near 4.8 kA.

Finally, the ECRH power scan included 12 discharges with heating power Q_{ECH}=200 kW; 4 discharges with Q_{ECH}=300 kW and 18 discharges with Q_{ECH}= 400 kW. In contrast with the previous scans, in this case the thermal diffusivity profiles are found to have an overall increment in 0.2<ρ<0.6 (not shown) when Q_{ECH} increases: χ_e roughly doubles when Q_{ECH} increases from 200 to 400 kW. In the density gradient region (ρ≈0.7) there is still an increment but quite less significant. More experiments are needed to improve the confidence levels in this scan.

References

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