EXPERIMENTAL DETERMINATION OF THE LOCAL HEAT CONDUCTIVITY COEFFICIENT $\chi_e(r)$ IN THE W VII-A STELLARATOR

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The local electron thermal conductivity coefficient $\chi_e(r)$ has been measured applying a modulation and correlation technique to the stellarator plasma of Wendelstein VII-A ($R = 2.0$ m, $a = 0.1$ m, $l = 2$, $m = 5$). The method is based on the fact that the power deposition of electron cyclotron heating (ECH) is locally well defined in the plasma centre. If the deposited power is modulated with proper frequency and amplitude, a heat wave is generated whose outward propagation is dominated by electron thermal conductivity and which is detectable by temperature sensitive diagnostics. Amplitude, $\Delta T_e(r)$, and time lag, $\Delta t(r)$ (or phase), relative to the generating signal as function of distance, r, to the plasma centre determine $\chi_e(r)$, the quantity of interest /1/.

We used a single gyrotron (70 GHz, 200 kW, 100 ms) for plasma build-up and heating. Its output power, P_{No}, was square wave modulated with amplitude ΔP_N after reaching quasistationary plasma parameters. The transient electron temperature, $T_e(r)$, has been determined at eight discrete radii, r_i ($i = 1...8$), on the high field side, $r < 0$ ($-a \leq r \leq +a$), of the plasma column by means of a multichannel heterodyne radiometer /2/ measuring the electron cyclotron emission (ECE).

The time lag $\Delta t(r_i)$ of the electron temperature modulation $T_e(r_i,t) = T_{eo}(r_i) + \Delta T_e(r_i) \cdot e^{i\omega t}$ was evaluated via Fourier transform of the cross-correlation function interconnecting the modulating signal and the response to it. Different modulation frequencies $\omega/2\pi$ between 100 and 1000 Hz and different types of discharges (see below) have been investigated.

The evaluation of the experimental data is based on the following theoretical model: In an axisymmetric geometry the balance equation for the electron energy W is used: $\partial W/\partial t = \mathrm{div}\, Q + P_N - P_L$, where the perpendicular heat flow Q is given by $n(r)\, \chi_e(r)\, \mathrm{grad}\, T_e(r)$ (n being the time independent electron density). P_L are the power losses via ion channel and radiation. All transport processes not related to the electron temperature gradient are neglected. Purely sinusoidal power modulation $P_N(r,t) = P_{No}(r) + \Delta P_N(r) \cdot e^{i\omega t}$ and electron temperature response as given above are assumed. Electron temperature dependence for both the heat conductivity coefficient $\chi_e(r)$ and the power loss P_L is considered by lowest order Taylor expansion in time. Since the temperature modulation is small, $\Delta T_e/T_{eo} \approx$ some per cent, the balance equation splits into an equation for the electron temperature $T_{eo}(r)$ (stationary balance) and an equation for the complex modulation amplitude $\Delta T_e(r)$ which is solved numerically and fitted to the experimental quantities to gain $\chi_e(r)$.

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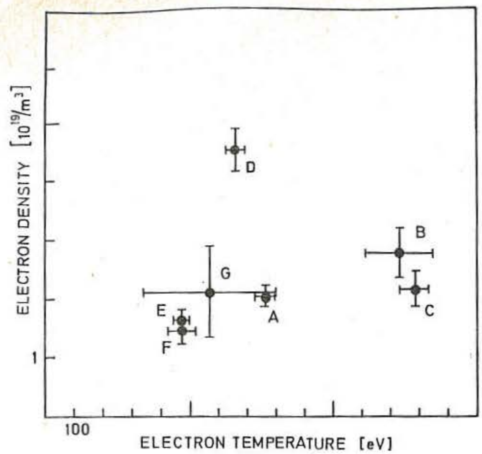

Fig. 1: The parameter range of the different types of discharges investigated.
Discharge A: $\bar{\iota} < 0.5$, $I_p = -4$ kA, B: $\bar{\iota} < 0.5$, $I_p = +4$ kA,
C: $\bar{\iota} > 0.5$, I_p = free, D: $\bar{\iota} < 0.5$, I_p = free, E: $\bar{\iota} = 0.2$, $I_p = -2$ kA,
F: $\bar{\iota} = 0.2$, I_p = free, G: $\bar{\iota} < 0.5$, I_p = free.

Different types of discharges have been investigated to check the χ_e-dependence on rotational transform and shear and on the main toroidal field. Figure 1 gives central electron temperature and density for six different types and the corresponding changes during the discharges (bars). The changes are usually monotonic. Discharges A to F correspond to 2.5 T main field, first harmonic ordinary mode EC-heating. Type G is conducted at 1.25 T, second harmonic extraordinary mode ECH. Except in case D, the discharges are guided well below the cut-off density, $6.2 \cdot 10^{19}/m^3$ for A-F and $3.1 \cdot 10^{19}/m^3$ for G respectively, to avoid significant refraction of the ECH beam. It is a crucial experimental condition for the applicability of the modulation method that clear separation between the power deposition and the zone of observation is accomplished. In Wendelstein VII-A with plasma radius < 10 cm, this condition is difficult to fulfill. The power deposition profile is at least 5 cm wide, so heat wave propagation can be observed only between 3 and 8 cm in maximum. The electron temperature profile should have its gradient regime clearly outside the deposition zone and the electron density profile should, according to the model, be as broad as possible. In addition electron temperature and density should be high enough to assure high single pass absorption of the ECH beam to avoid wall reflections with subsequent boundary layer absorption.

The rigorous experimental demands are verified best with type A. The results are discussed in detail in reference /3/. Beyond that Figure 2 presents the results in comparison to theoretical results on the basis of neoclassical transport /4/, clearly demonstrating the usefulness of the method. Only an upper bound for the local transport coefficient can be derived at best from the other discharge types investigated. Only small

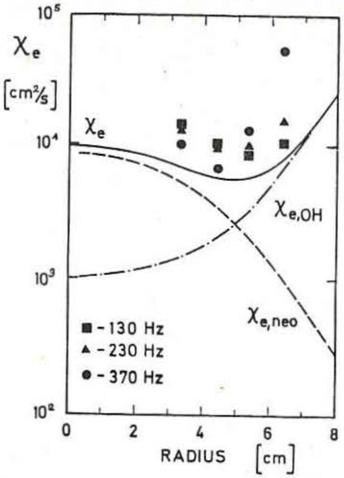

Fig. 2: χ_e-results obtained with type A discharge for different modulation frequencies in comparison to theoretical studies based on neoclassical theory, $\chi_{e,neo}$. An anomalous contribution as found in OH discharges, $\chi_{e,OH}$, is included. # 57829 - 57896.

time lag is found in type E and F discharges which is even decreasing for r > 5 cm due to incomplete single pass absorption followed by wall reflections and diffuse power deposition in the plasma boundary layers. Still stronger decrease is observed with type D because ECH beam refraction doesn't allow for localized deposition in the plasma centre.
Discharges B and C have rather narrow electron temperature profiles with gradient regime not sufficiently separated from the deposition zone for clear conclusions.

Figure 3 gives the evaluation of discharge type G, ECH at 2nd harmonic X-mode. Unfortunately the discharge is not as stationary as types A-F. Both central electron temperature and density vary by more than a factor of two during the modulated heating phase. In addition they are connected with profile changes. The rather large discrepancy to the results evaluated from the stationary balance, based on the profiles as measured at the beginning of the modulated phase, may be due to these imperfect experimental conditions.

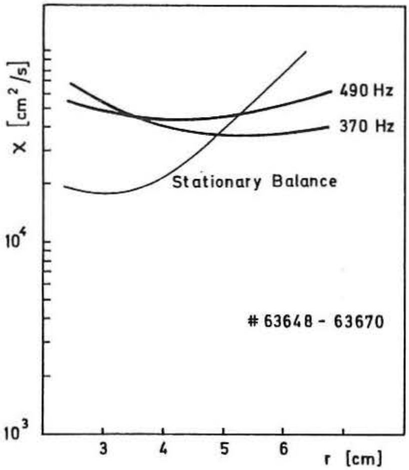

Fig. 3: $\chi_e(r)$ evaluated for a 1.25 T, type G, discharge heated with 2nd harmonic ECH. Included is the result obtained from the stationary balance.

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