Thermal electron transport in LHCD plasma regimes with low and reversed magnetic shear in FTU

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1. Introduction

The link in steady state conditions between the electron transport and current spatial profile is studied in FTU (Frascati Tokamak Upgrade R_0 = 0.935 m, a = 0.3 m, B = 4-8T) using non-inductive current drive. Discharges are realized where, during off-axis full LHCD (Lower Hybrid Current Drive), temperature spatial profiles ($T_e(r)$) evolve to peaked central profiles with variation of the temperature gradient. The MHD exhibit a full stabilization of sawtooth and m=1 mode, till t=.63s in LHCD (see fig. 1), after the mode m=1 appears and persists during LH. In this paper the results of a preliminary transport analysis of these discharges are reported. The thesis of the work is: a wave deposition profile obtained from standard ray-tracing Fokker-Planck code [1,2], modified for allowing radial diffusion of fast electrons [3], coupled to a transport code which use a Bohm-gyroBohm [4] transport model checked on ITER data base correctly predict the temperature profile. The paper is organized as follows: in section 2 the main measured quantities characterizing the reference discharge #12975 are reported, in section 3 the results of the transport analysis are reported and discussed.

2. Features of FTU discharges with Full LHCD

Discharges with full LHCD on FTU are realized at low density, low current where a power of 900 kW is enough to produce the full current drive by lower hybrid with asymmetric spectra. Typical traces of these discharges are shown in fig.1, where the measurements of the main plasma parameter are reported. Deuterium plasma parameters are n_{e20} = 0.45, I_p = 0.35 MA, B = 5.5 T. The LH power of 0.9 MW lasts 0.5 s, launched at $n_{||0}$=1.55. The full current drive is attained and the loop voltage drops to 0, when the temperature at center is 4.3 keV (while in ohmic regime it is 2.1 keV), and the MHD is completely stabilized, till t=.63s, when the mode m=1 appears, while in ohmic phase a sawtooth is clearly measured on the central channels of fast ECE polychromator. The Z_{eff} measurement obtained by visible bremsstrahlung and Thomson Scattering data has the value of Z_{eff}=3.2 during full LHCD. The evolution of the electron temperature spatial profiles measured by the FTU Thomson Scattering System [5] is shown in fig. 2: the T_e profile raises starting from the spatial channels at mid radius, while the peaking factor i.e. the ratio between the center T_e value and its volume average (T_e (0)/ $\langle T_e \rangle$) value increases from 5 to > 6.2. The evolution of the gradient of the pressure profiles shows a clear raise of the pressure gradient starting from mid radius channels, peaking by a factor at least two during full LHCD. The wave deposition can be inferred from hard-X behaviour. The hard-X spatial profiles were not available for the shot #12975, but for a similar shot (#15330) it were available: the radial profiles of hard-X in the ohmic phase and LHCD phase show an

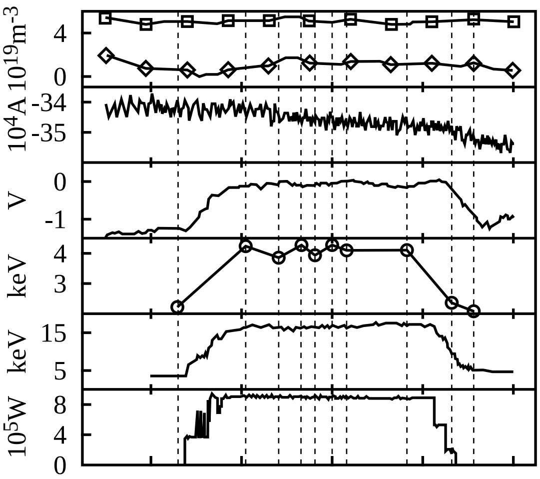

Fig. 1 – Traces of main plasma parameters. For shot #12975: First line average electron density; £ R=0.935 m, , = 0.917 m; *Second line plasma current; Third line vloop; Four line $Te^{TS}(0)$; Five line fast ECE at center; six line LH coupled power*

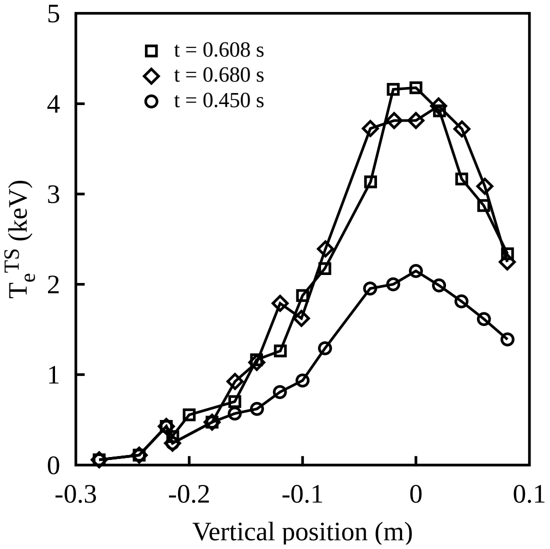

Fig. 2 – Temperature profiles from Thomson Scattering system. The mode m=1 is present at t=.68s

increase of hard-X for energies 100-300 keV, in the region off-axis at r/a = 0.3. The data for the shot #12975 have been simulated using two different codes both incorporating the Bohm-gyroBohm model for the electron transport , while the neoclassical transport for the ion was used.

3. Lower hybrid wave deposition profiles and simulation of the electron temperature profiles

A standard ray-tracing Fokker-Planck code was used to calculate the Lower Hybrid wave deposition profile: the fig. 3b) shows this profile for the shot #12975. A off axis deposition profile is obtained, peaked at r/a=0.3,with a FWHM (full width at half maximum) spatial distribution of $\Delta r/a=1/6$. The calculated wave deposition from this code was inserted in the JETTO code [6] as wave induced current profile to predict the electron temperature spatial profiles. The result is that neither the shape nor the peak is reproduced. The comparison between calculated and measured temperature profiles is much better when the wave deposition is changed to a larger profile, i.e. peaked off-axis at r/a=0.3 as given by Fokker-Planck code but with gaussian FWHM of $\Delta r/a=0.3$ (see fig. 3a), the results are shown in fig. 4. The deposition profile used is from one side in agreement with hard-X measurement, and from the other side is consistent with a broadening of the current profile due to radial diffusion of fast electrons. Indeed a 3D-Fokker-Planck calculation [3] including radial diffusion of fast electrons confirm the broadening of the deposition profile, using a fast electron diffusion coefficient of D=0.07 m^2/s. The ASTRA transport code is also used to calculate the electron temperature profiles from this last wave deposition profile, using the Bohm-gyroBohm transport model given in Ref. [4]. A preliminary result of this calculation shows an agreement with the experimental data. The evolution of the safety factor spatial profiles obtained by the JETTO code is shown in fig.5, featuring a deep minimum at r/a=0.3, with a q value less than 2. An estimate of the global confinement time (τ) lead to a value of $\tau_{LH}/\tau_{\ ohmic}$ =0.9, resulting in $\tau_{\ LH}/\tau_{ITER89}P$=1 in agreement with previous calculations [7].

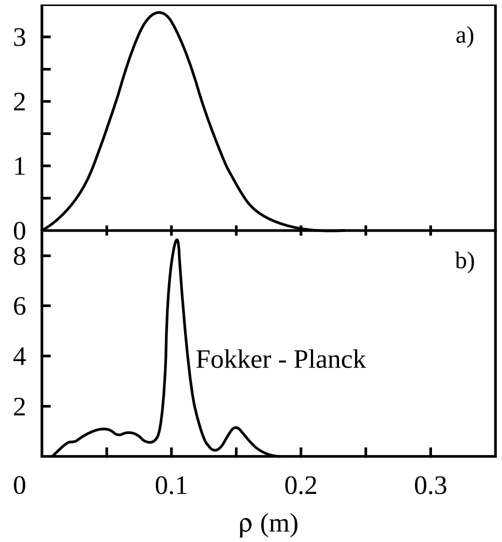

Fig. 3 – Lower hybrid deposition profiles: a) gaussian; (including diffusion of fast selections) b) Fokker-Planck

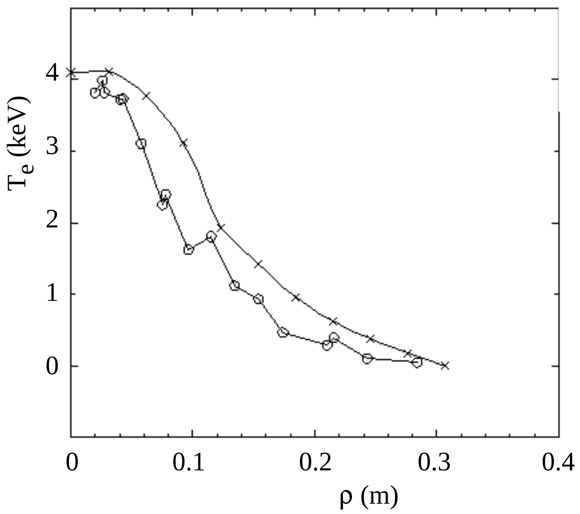

Fig. 4 – Simulated and measured temperature profiles:Te measured by Thomson Scattering (circles), and calculated by JETTO (crosses) for t=.68s, using the wave deposition profile given in Fig. 3a

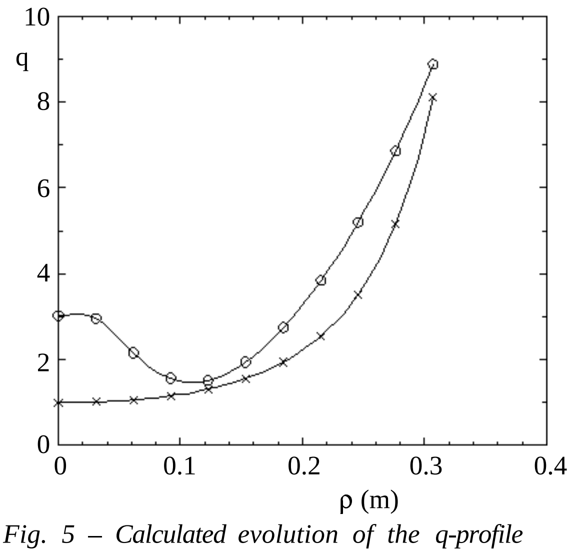

Fig. 5 – Calculated evolution of the q-profile before (crosses, t = 0.45) and during LHCD (circles , t = 0.68 # 12975)

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