*31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-2.104 (2004)*

Benchmarking of LHCD numerical modelling on FTU discharges and application to ITER-FEAT scenarios

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1.Introduction. Calculations are carried out by ASTRA [1] code. The Lower Hybrid Current Drive (LHCD) model combined to ASTRA is the ray tracing 1-D ($v_\parallel$) Fokker Planck package FRTC [2,3], that has been already benchmarked on FTU LHCD experimental data [4]. In the Fokker Planck model ad hoc corrections to the collision operator account for 2-D effects, such as pitch angle scattering [5]. The LHCD calculation is carried out on FTU experimental data. Plasma parameters profiles are set to the experimental values time by time, while the magnetic flux diffusion equation is solved in the presence of the LHCD component calculated by the model.

In this paper, this model is applied, first, to the FTU experiment where a test [6] of an LH launcher, suitable to be used in the ITER tokamak environment, has been successfully performed. Such an antenna, called Passive Active Module (PAM) antenna [7], launched about 200KW of power into plasma of $0.4\text{-}0.5 10^{20} m^{-3}$. The results of this experiment are detailed in ref. [6]. The LH driven current and the current density profile are calculated and compared to the experimental findings. In particular HXR measurements allow checking the calculated current density profile. Following the experiments, the LHCD by PAM is compared to LHCD by conventional antenna in FTU.

After such a benchmarking, modelling of LHCD in ITER FEAT scenarios [8,9] is reported. Parasitic absorption of LH wave power by α particles is calculated as a function of the fast α density at the location of the absorption [3]. A quasi-linear (QL) Fokker Planck model for the α distribution function is used providing the α distribution function. Such a calculation indicates that a frequency $f \geq 5$ GHz has to be used in ITER to avoid detrimental effect of α absorption on the LHCD efficiency.

We conclude the analysis of the ITER scenarios [8,9] presenting and discussing the current density profile and the CD efficiency provided by our model.

2.Modelling of the LHCD experiment with PAM launcher

The figure 1 shows the temporal behaviour of the discharge. It is a low density, low temperature discharge where in the first stage (0.5< t <0.7 sec) almost 200 KW of LH power are launched into the plasma from the PAM antenna. Then (0.85< t <1sec) 300 kW are injected from the conventional antenna, and finally (t >1 sec) both conventional and PAM antenna fire a total power of 400KW (see fig.1 b). The LH current, calculated by the numerical model, is shown in figure 1a) and compared to the ohmic current. I_{LH}/I_{OH} results to be 15- 30%. It is important to notice that the conventional and the PAM antenna are located in a different, opposite, poloidal position, one at $\theta \sim -30^0$ and the other at $\theta \sim +30^0$. The ray trajectory analysis shows that the rays reach the plasma centre in the case of the PAM launching position, while stay far from plasma centre for the conventional launching position. This is illustrated in fig.2, where trajectories and $n_\parallel$ along the ray trajectory are shown for PAM position (Fig. 2a) and conventional position (Fig. 2b). As a consequence, the calculated current density profile has a more central peak in the case of the PAM launch (Fig.3a), while it is peaked more off axis in the case of the conventional launch (Fig.3b). In the case of the simultaneous launch, a broader current density profile is predicted (Fig.3c). In figure 3, the calculated current density profile is compared to the HXR measured profile at 3 different times corresponding to the different launches (PAM, conventional and combined). The HXR measured profiles seem to be reminiscent of the predicted sensitivity to the launching position. The predicted J_{LHCD} peaks mostly where HXR peaks. However the HXR profiles are broader then the calculated current density profiles. This seems to be a typical feature of LHCD in FTU at low density [4], and can be attributed to the spatial diffusion of fast electrons [4]. The calculated current drive efficiency of PAM and Conventional spectrum are similar, both of the order of 0.08 10^{20}AW^{-1} m^{-2}.

3. LHCD modelling in ITER Q=5 scenario

We use, as a plasma target for our LHCD modelling, the ITER scenario_4 of ref. [8,9]. This is a steady state, shear reversal, Q=5 scenario, characterized by the following parameters: R=6.2m, a=1.86m, B_T=5.3T, I_P=9MA, $<n_e> = 0.67\ 10^{20}$ m^{-3}, $\beta_N = 2.5$. The bootstrap drive, I_{BS}, and the non-inductive current drive, I_{CD}, sum up to give the total plasma current. According to Ref. [8] the main contribution to I_{CD} comes from the NBI injection, while 30 MW of LHCD drive the off-axis part of I_{CD}. In ref. [8] the current density profile, driven by LHW, J_{LHCD}, as well as, the current drive efficiency were not calculated but simply assumed. On the contrary, here, we calculate the LH power deposition and current density profile by the full ray tracing Fokker-Planck model. Furthermore we evaluate the parasitic alpha absorption at different frequencies (namely 3.7 and 5 GHz) in order to give an element for the LHCD frequency choice in ITER.

According to our calculation, in this scenario LHW absorption takes place during the first pass and ray trajectory is very similar both at 3.7 GHz and at 5 GHz.

We calculate the α absorption for three different α density profiles. The first one is the fast α density profile based on the slowing down process. The other two profiles, normalized to the same volume integral (same α number), are broader. In this way we try to take into account, heuristically, effects such as large banana orbit of trapped alphas. As a matter of fact the latter, even though generated at the plasma center, can reach the peripheral absorption layer during the large radial excursion of their banana orbit, before completing the slowing down, thus contributing to wave absorption.

In Fig.4 a) the fraction of power absorbed by α's at 3.7 GHz and 5 GHz is shown for the three α density profiles described before. In the abscissa the value of the local α density, taken at the absorption radius (ρ=0.7), is reported. At 3.7 GHz, α's absorption is 8% at the lowest density for fast α's (~1 10^{16} m^{-3}), nominal for this scenario, and it reaches 18% when α's density increases up to 7 10^{16} m^{-3}. On the contrary, at 5 GHz, α's absorption is always negligible.

In fig.4 b), the QL α distribution function, F_α at the absorption layer is shown for two values of the LH power (20 and 40 MW). In both cases, F_α drops quickly, at velocities larger than the birth velocity, so that no dangerous fast α's tails are expected to hit the wall. The normalized QL diffusion coefficient shown in the same figure is less than unity in both cases.

Figure 4 c) shows the current density profile by 28 MW of LHW at f=5GHz for the scenario 4. The total current is 1.152MA divided in I_+ =1.3MA, localized about ρ=0.7 and I_-=-0.15MA localized more peripheral at ρ=0.9. The total CD efficiency, $\eta=R_0\, I_{TOT}\, n/\, P_{TOT} \sim R_0\, I_+\, n/\, P_{TOT}$ results to be $\eta \sim 0.2 AW^{-1}\ 10^{20} m^{-2}$. This value is approximately 70% the CD efficiency, $\eta=0.3AW^{-1}\ 10^{20}m^{-2}$, assumed in Ref. [8]. We would recover that 30%, if we disregarded the power in the negative lobe. In other words the present ray-tracing Fokker-Planck model gives a CD efficiency $\eta=R_0 I^+\, n/\, P^+$, $\eta=0.3AW^{-1}10^{20}m^{-2}$, that reduces to $0.2AW^{-1}10^{20}m^{-2}$ simply by taking into account the directivity of the power spectrum.
A good qualitative agreement is also found in the current localization, between the results of our calculation and the J_{LHCD} profile assumed in ref. [8] (see ref.[3]).

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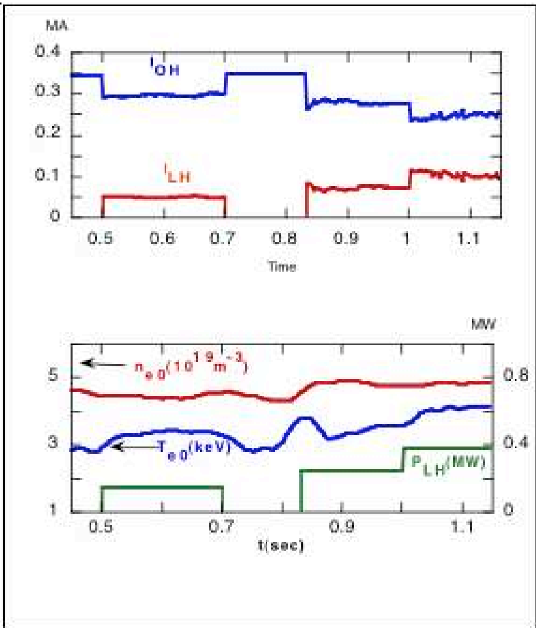

Fig.1: *a) Calculated LH and ohmic current during the discharge. b) Central electron density and temperature and P_{LH} waveform.*

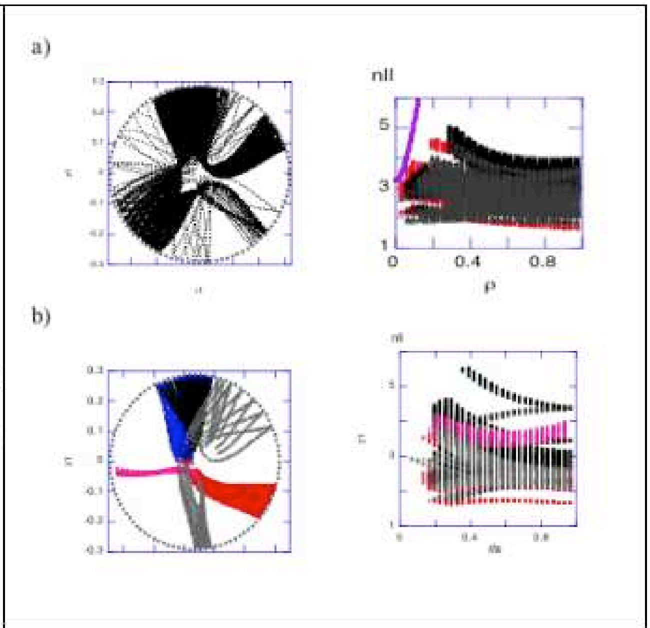

Fig.2: *ray trajectory and $n_{//}$ vs. r, along wave trajectory a) for Pam spectrum, top launch. b) For standard grill spectrum, bottom launch.*

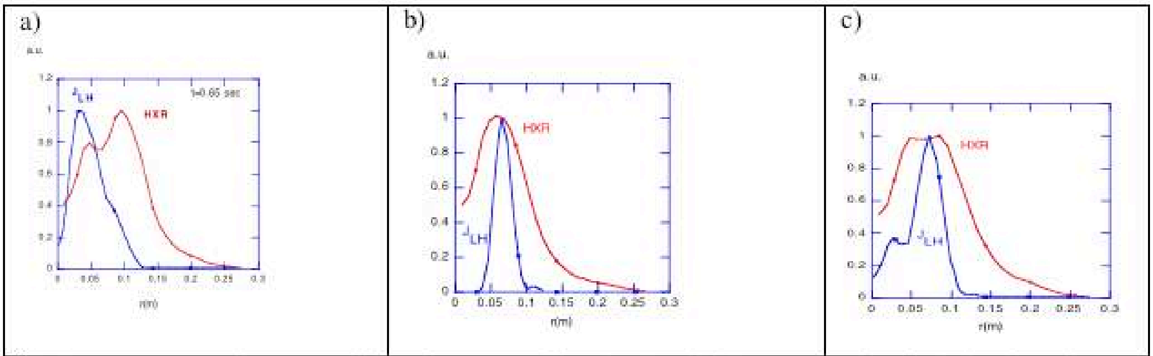

Fig. 3: LH current density profile and HXR profile. a) PAM b) Conventional and, c) Combined spectrum

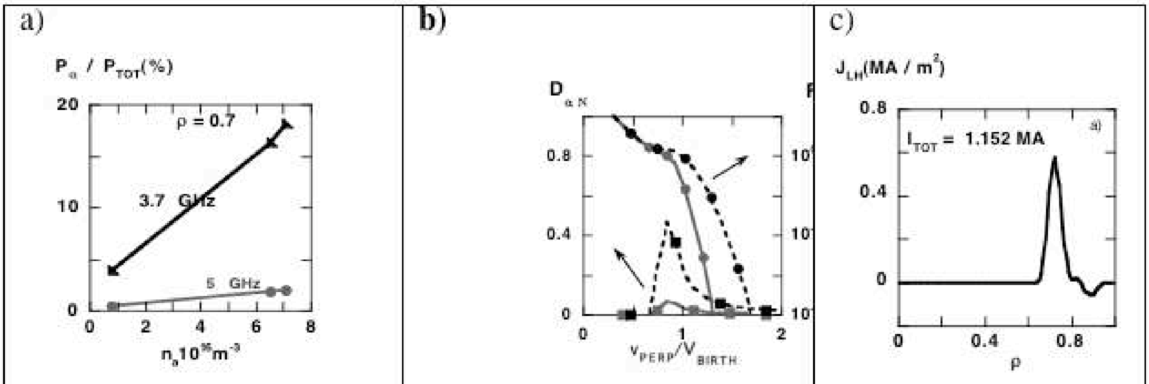

***Fig.4** ITER scenario_4, a) fraction of power absorbed by α's, as a function of the local α density at 3.7 GH and 5 GHz. b) α distribution function (on the right) extending beyond b_{irth} for 2 different LH power level (P=20MW grey lines and P=40MW black dotted lines), the relevant normalized LH QL diffusion coefficients are shown on the left. c) Total LH current density profile*