Sensitivity of central electron temperature estimations with the multi-foil diagnostic to profile transitions in TJ-II NBI-heated plasmas

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Introduction

Operation under full lithium-coating walls [1] has enabled for an improvement of plasma performance in the TJ-II stellarator [2]. In the lithium wall scenario, electron density and radiation profiles of neutral beam (NB) heated plasmas frequently evolve ‘spontaneously’ from highly peaked, concomitant to central impurity accumulation, to markedly broad, with lower central Z_{eff} profile but prone to radiative collapse [3, 4]. For the experimental investigation of the driving mechanisms for such a transition, series of reproducible discharges are necessary to determine the dynamic evolution of plasma profiles, due to the fact that the TJ-II Thomson scattering (TS) system operates in single-shot mode. To solve this inconvenience, a Bayesian method has been applied to reconstruct most of the electron density profile making use of reflectometer and interferometer signals [5], and the implementation of a multi-channel electron temperature (T_e) diagnostic, based on the filters method [6], is under way. In a first term, single-channel systems with two (M2F) and four filters (M4F), probing the core region (i.e., $0 \leq r \leq 0.4$ a, being a, the minor plasma radius), have been tested to assess the feasibility of that method to determine T_e in TJ-II NB heated plasmas. In previous works [7, 8], the detailed design and the data analysis procedure followed to obtain the experimental estimations of T_e with the M4F system were described. In short, the filter thicknesses, sensors type and detection geometry were chosen on the basis of TS, VUV and soft x-ray (SXR) tomography diagnostics information. Compared with TS data, the M4F results showed a systematic T_e underestimation of about 10% for a large number of discharges, obtained under different operation scenarios, during the last campaigns. The results presented in this paper describe how the use of more accurate profiles in data analysis leaded to the agreement, within their experimental errors, of M4F estimations and TS measurements. Additional information from the routinely available global and SXR emissivity profiles has enabled for the determination of the time evolution of T_e in a discharge showing profiles transition without *ab initio* TS information.

Experimental procedure

The analysis of the M4F (four silicon photodiodes with beryllium filters of 23, 30, 43 and 75 μm thicknesses) data is carried out using the radiation code IONEQ [9], that needs as main input parameters the electron density and temperature profiles, impurity species and concentration, transport coefficients, filters type and thickness. In a first approximation, the M4F signals from NB heated discharges were analysed using fixed "standard" profiles ($T_e(\rho) = T_e(0)[1-\rho^{3.5}]^3$, $n_e(\rho) = n_e(0)[1-\rho^{3.5}]^{2.5}$, *i.e.*, the most frequently determined with the TS diagnostic in NBI discharges) and variable concentrations of the intrinsic impurity species of TJ-II, according to the VUV survey diagnostic spectra. Fig. 1(a) shows the comparison between the core ($0 \leq r \leq 0.4$ a) averaged T_e estimations from TS (Te0_TS) and M4F (Te0_M4F) systems, for different magnetic configurations, density ranges, impurity contents and NB input powers, using the "standard" profiles. As abovementioned, the M4F system tends to underestimate T_e in a 10% in average, but it must be emphasized that the analyzed plasmas had different profiles and sizes. To probe the influence of the used profiles on the lack of accuracy of the fitting, the actual T_e and n_e profiles obtained with TS for each discharge were used to find the best fit for T_e (Te0_M4F), while keeping the rest of the input parameters unchanged. In general, a significant improvement was found but, as can be seen in Figs. 1(b), (c) and (d), the discrepancy between Te0_M4F (full dots) estimations and Te0_TS values, seemed to depend on the magnetic configuration. In particular, for shots with configuration '101_42_64' ($1.53 < \iota/2\pi < 1.66$), the observed discrepancy is still rather large (see Fig. 1c). Here it must be mentioned that in many of the shots of this configuration, TS data were obtained after the confinement transition, where radiation profiles rapidly change.

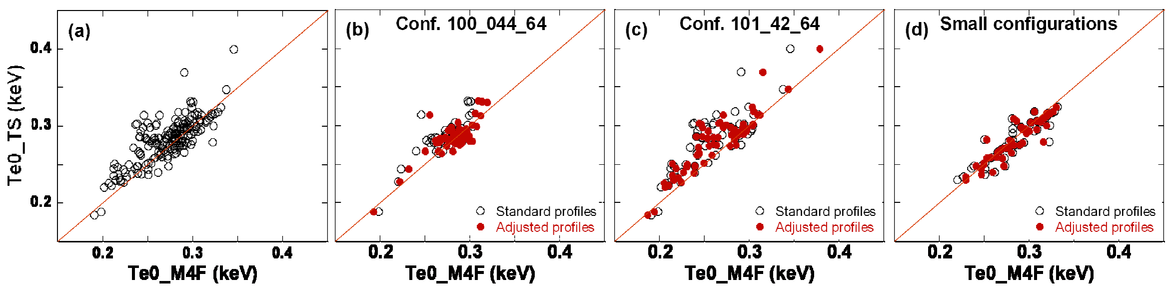

Figure 1. Comparison of electron temperatures obtained with the M4F, for standard and adjusted profiles, and TS diagnostic: (a) all configurations, (b) conf. 100-044_64 ($1.55 < \iota/2\pi < 1.65$), (c) conf. 101_042_64 and (d) small configurations.

Using a series of reproducible shots from which TS profiles were measured in different times, a more detailed analysis to check the sensitivity of the M4F estimations to profile shape could be performed. Fig. 2(a) shows the time history of some relevant parameters of one representative discharge (the vertical dotted line approximately marks the transition between peaked and dome profiles) and Fig. 2(b), the comparison between M4F and TS data for six discharges of the series. Full dots are the TS values, and open circles correspond to T_e estimations with standard profiles. It can be seen that the higher deviation occurs for shots with dome-shaped profiles (in this series, from t > 1150 ms).

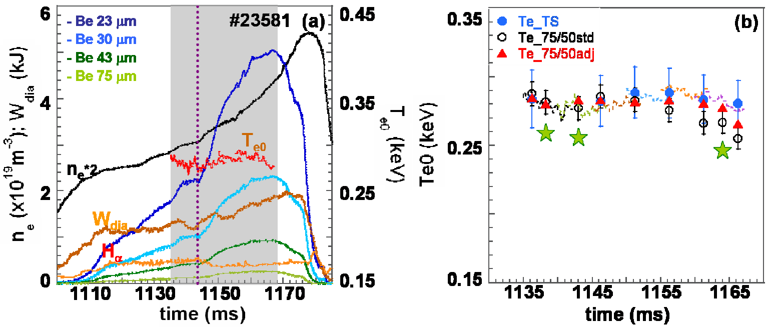

Figure 2. Time history of the electron density (n_e) plasma energy (W_{dia}), four M4F signals and one H_α monitor. T_e was evaluated during the period shadowed in grey.

As the M4F system is intended to provide the temporal evolution of T_e, it is necessary to resort to other data that permit to characterize the profile type. After establishing a rough correlation between the profile shape and radiation peaking factors in different energy windows from the bolometry and SXR tomography systems [10, 11], a further refinement in the fitting procedure was obtained (see triangles in Fig. 2(b)). Once this correlation was established for these discharges, we calculated three intermediate points, at the times marked with full stars in Fig. 2(b), where no TS data were available. The composition shows a discrete temporal evolution of T_e that is coherent with the rest of plasma parameters. Then, the continuous evolution of T_e in shot #23581, represented in Fig. 2(a) as T_{e0} and in Fig. 2(b) as a dotted line, was performed using the profile shapes adequate to the temporal evolution of the radiation peaking factors. After this correction, it still seems that, at the transition, there is not a drop in central electron temperature.

Injections of low-Z impurities were performed as a controlled method to trigger profile transitions [12]. Fig. 3 (see (a) and (b)) illustrates the time history of relevant parameters of two identically pre-programmed low-power NB-heated discharges, of which in #23626, a N_2 pulse of 4ms length was puffed. Following the procedure described above, the time evolution of T_e for the reference discharge (#23624) was evaluated and the basic plasma composition to start the reconstruction of the discharge with injection was determined. Then, after the injection time, the extrinsic impurity was considered in the analysis together with the modified profiles. In fig. 3(c), it is shown the time evolution of the core T_e for both discharges. In this case, the profile change entails a drop in the core electron temperature.

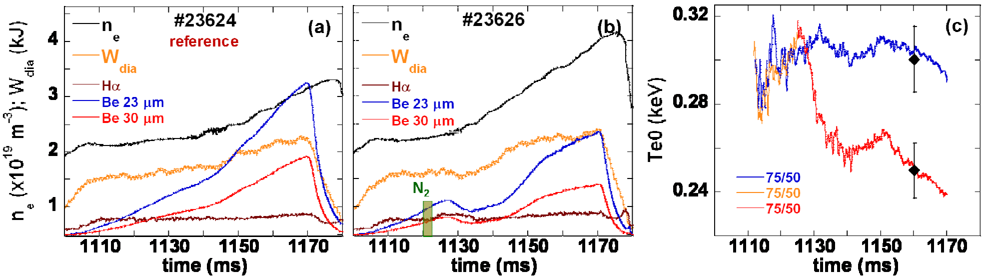

Figure 3. Time evolution of global parameters n_e, W_{dia}, H_α and two M4F signals (both M4F and H_α are in a.u.) for (a) reference discharge, and (b) discharge with a N_2 pulse. In (c) T_{e0} is represented for both discharges, with the TS electron temperature depicted by black diamonds.

Conclusions and future work

The use of adequate profiles for electron density and temperature in M4F data analysis has enabled for an excellent agreement with TS measurements. The M4F system has been used to follow the core electron temperature during profile transitions, both spontaneous and forced. Even though it is known that edge electron temperature falls immediately after impurity injection [4] or in spontaneous bell-dome transitions [13], the presented results point that in the latter, electron temperature does not decrease while in forced transitions there is a clear temperature drop in the plasma centre. The spatial resolution necessary for the investigation of the mechanisms involved in transitions will be available in the near future, with the use of the recently installed SXR multi-channel array based in the two-filter method.

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