Core electron temperature diagnostic for high-density plasmas in the TJ-II stellarator

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Introduction

A new diagnostic to monitor the electron temperature with temporal and spatial resolution has been proposed for the TJ-II stellarator [1] based on the method known as the two-filters technique [2]. It will be destined to substitute the 16-channel heterodyne ECE diagnostic to give the time evolution of the electron temperature profiles when plasma electron density is higher than 1.7×10^{19} m^{-3}. In the last experimental campaign, a single-channel prototype consisting in a soft x-ray system equipped with four filters of different thicknesses has been constructed and installed in TJ-II. It is well known that this method to determine electron temperature has two main drawbacks, namely, the deviation of the electron energy distribution function from a Maxwellian and the spurious pollution of the continuum part of the soft x-ray spectra due to line radiation emissions from plasma impurities. Therefore, as it is done in other magnetic confinement devices in operation [3, 4], proper interpretation of data obtained with this diagnostic requires the help of impurity transport codes. As was explained in a previous work [5], the IONEQ code [6] has been used initially to design the diagnostic setup and, once experimental data were obtained, to find the best fit to determine the electron temperature in TJ-II plasmas.

Lately, TJ-II is operated with lithium-coated walls [7] and, according to the VUV survey diagnostic [8], the dominant impurities are lithium, carbon, oxygen and fluorine. Besides, after Thomson scattering (TS) and pulse height analyzer diagnostics it is known that electron temperature rarely exceeds 0.4 keV at the core region. As will be discussed below, this information was used to select the filters of the four-foil prototype (M4F). First experimental results obtained in low-power (< 400 kW) Neutral Beam heated discharges are reported in this communication. Comparisons with TS data are presented and tests on the M4F sensitivity to plasma composition are also addressed.

Experimental procedure and first results

The used prototype consists in four AXUV photodiodes (from IRD [9]) looking at the same plasma region through Be-filters with thicknesses of 23, 32, 45 and 76 μm. Fig.1 shows a TJ-II schematic top view where the M4F location is indicated. As can be seen, two M4F systems have been indeed installed (C1-Top and D8-Bottom) that see equivalent plasma cross-sections and will serve for probing up-down symmetry.

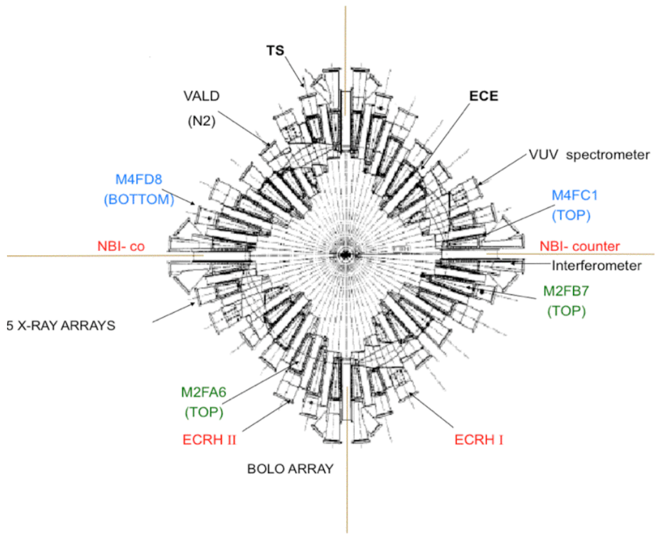

Fig.1. Top view of TJ-II. Location of M4F systems and other diagnostics of interest are indicated.

The IONEQ code was used to simulate the plasma emissivity and for that, electron temperature and density profiles obtained with TS, and typical plasma composition and transport coefficients for NB heated discharges were taken into account, as well as, detailed 3-D plasma volume viewed by the detectors for different configurations.

In order to test the reliability of the M4F diagnostic, comparisons with central values of electron temperature (T_{e0}) measured with TS system have been done (Fig. 2). Discharges with different magnetic configurations and with different gas injections were used. It must be mentioned that although wall lithiumization has enabled for a better density control, plasma profiles can be strongly variable during the NB pulse. This profiles variation fully explains the observed discrepancy increase at lower temperatures. As the presented diagnostic is intended for giving the time evolution of electron temperature, possible profile effects uncertainty will be addressed in immediate future with the help of the TJ-II soft x-ray tomography system [10].

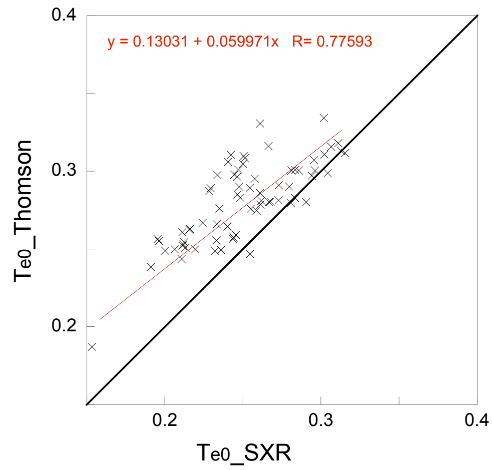

Fig. 2. Comparison between the electron temperature measurements obtained with the M4F and Thomson Scattering diagnostics.

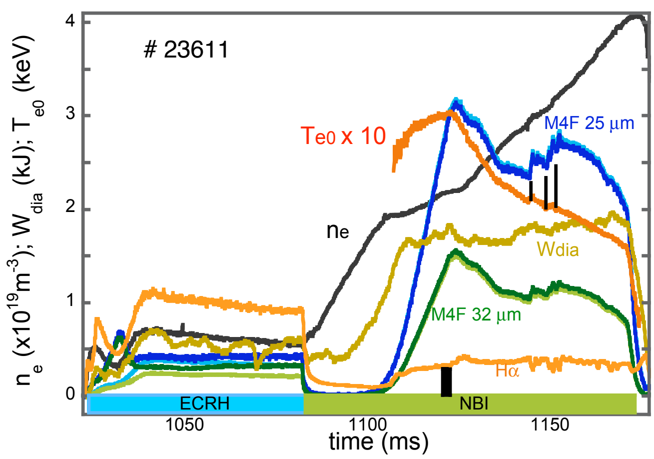

Fig. 3 Time evolution of #23611 TJ-II discharge.

Fig. 3 presents the time evolution of some of the signals of the M4F diagnostic together with others from global parameter monitors corresponding to a complete discharge of TJ-II, heated both, by ECRH and NBI (#23611). During the NBI phase a short pulse of N2 was injected. Equivalent signals from the two M4F diagnostics show a clear departure during the ECRH phase, especially at low densities, due to the already observed asymmetry of convective losses [11]. This fact, together with the low signal-to-noise ratio, disqualifies this diagnostic to reliably operate in ECRH plasmas. On the contrary, during the NBI phase, excellent agreement between the two M4F sets signals and an adequate signal-to-noise ratio are observed. It can be also seen that the deduced time evolution of T_{e0} correlates with the other plasma monitors (n_e and W_{dia}) during the injection of a N_2 pulse. Moreover, in this discharge, at least three short-lived time fast transitions to a better confinement regime can be observed (see the H_α monitor) that have an impact, although small, on the T_{e0} signal. Thus, a change in confinement is reflected in this signal under the form of oscillations in magnitude as it can be seen around 1145-1155 ms. The red line depicted represents the averaged core electron temperature calculated with the different signal-pairs ratios obtained with the M4FC set during the NBI heating phase.

Tests on the sensitivity to the plasma impurity content were performed using series of discharges with controlled injection of non-intrinsic low-Z impurities.

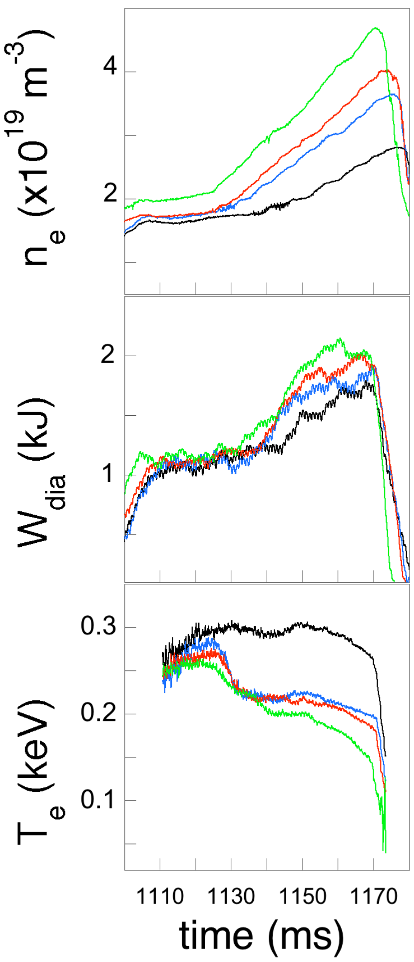

Fig. 4. From top to bottom: average line density, diamagnetic energy plasma content and estimated T_{e0}. Black, reference discharge (#23624); blue and red, two discharges with different N_2 pulses (#23626 and #23632) and green, N_2 pulse over a higher plasma density (#23633).

Discharges without injection (#23624 in Fig. 4), were used to establish a reference plasma composition. Then, series of shots either with the same density and different N_2 pulse lengths or with different density and same injections were produced. In Fig. 4, it can be seen the calculated T_{e0} for the reference shot and for three discharges of one of the produced series, belonging to the same magnetic configuration. Both, absolute values and temporal evolution showing the rapid cooling due to the impurity entrance, are in excellent agreement with the TS measurements and power balance estimations.

Conclusions and future work

In this paper it was shown the viability of the M4F system as a suited diagnostic for electron temperature estimation in high-density plasmas, as well as, a tool for studying fast events. The discrepancies observed during the comparison with TS due to profiles variation, will be considered in short-term with the help of the SXR tomography system and, in long-term with the implementation of a multichannel M4F-array.

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[1] C. Alejaldre and the TJ-II Team, Fusion Technol. **17**, 131 (1990).
[2] T. P. Donaldson et al., Plasma Phys. **20**, 1279 (1978).
[3] P. Franz et al., Rev. Sci. Instrum. **77**, 10F318 (2006).
[4] L. Delgado-Aparicio et al., Nucl. Fusion **49**, 085028 (2009).
[5] D. Baião et al., Rev. Sci. Instrum., *in press* (2010).
[6] A. Weller et al., Report JET-IR(87)10 (1987).
[7] F. L. Tabarés et al., Plasma Physi. Control. Fusion **50**, 124051 (2008).
[8] K. J. McCarthy et al., *The Normal-incidence ultraviolet Spectrometer for the TJ-II and First Experimental Results* (Informes Técnicos Ciemat, 988, 2002).
[9] http://www.ird-inc.com/
[10] F. Medina et al., Rev. Sci. Instrum. **70**, 642 (1999).
[11] F.Medina et al., Plama Phys. Control. Fusion **49**, 385 (2007).