Electron temperature measurement by Optical Emission Spectroscopy in the low density plasma of the linear device GyM

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Introduction. Optical Emission Spectroscopy (OES) has been designed to be installed on the linear plasma machine GyM [1,2] as a non-intrusive diagnostic for the measurement of electron temperature (Te) profile, in addition to Langmuir probes. GyM is a machine dedicated to plasma turbulence studies [3] equipped with different diagnostic systems especially dedicated to density fluctuations. Therefore a non-intrusive technique to measure plasma parameters can give independent information to be used in theoretical and modeling analysis of turbulence structures evolution. The diagnostic collects the radiation emitted by plasma along a sightline estimating Te from the intensity ratio of H_α and H_β Balmer lines of atomic hydrogen, on the basis of a plasma corona model. As the measurement is integrated along the sightline, Abel inversion technique on more chords conveniently chosen will be used to obtain Te profile.

A first prototype has been implemented using a JAZ spectrometer (Ocean Optics) with 1.7 nm resolution, connected with an optical fiber to a collimator gathering visible light along a single sightline crossing the center of a poloidal section of GyM plasma column. To verify accuracy and quality of the results, some measurements have been repeated by a spectrometer with a higher resolution (Jobin Yvon - 0.06 nm) and compared; in this way a correction factor has been determined. Then a series of measurements in different plasma conditions has been made to compare OES results with those from probes. A good agreement has been demonstrated, even if the localization of the two diagnostics is not directly comparable (integrated for OES, local for probes).

Experimental setup. GyM is a linear device consisting of a vacuum chamber (diameter = 0.25 m, length = 2.11 m) mounted in a 0.13 T solenoid. The plasma is generated and sustained by a magnetron source (2.45 GHz, 1.6 kW CW) connected to the vessel through a rectangular waveguide, exploiting the cyclotron resonance absorption mechanism at B = 0.87 KG to ionize and heat the plasma. The diagnostic for Te measurements is based on a Langmuir probe array (LPA), with linear geometry and capable of a 16 cm vertical scan along the plasma column. The prototype of the OES system has been installed to collect radiation emitted by the plasma along a sightline in a plane perpendicular to the machine axis, with an inclination of 45°. The low resolution spectrometer (JAZ – Ocean Optics) and the high resolution one (JBY – Jobin Yvon) are alternatively connected to the collimator with an optical fiber (600 μm). Both the instruments consist of a grating monochromator equipped with a CCD and have been calibrated in intensity with the used optical fiber.

Theoretical model. The elaboration of OES data has been made on the basis of a steady-state corona model, valid for a low density, optically thin plasma [4]. In the present GYM conditions electron density always keeps lower than 10^{11} cm^{-3}, as required by the model and in accordance with Wilson and Athay criteria [5] represented in Fig. 1.

The model assumes a balance between the rate of collisional excitation by electron impact from the ground state, which depends on Te (Fig. 2), and the rate of spontaneous radiative decay, so that processes as excitation from metastable states, recombination, collisional excitation transfer between neighboring atoms, optical cascading and excitation by free electron collisions from upper states are considered secondary and neglected. Electron temperature is estimated from the H_α/H_β intensity ratio, known the electron impact cross sections [6], assuming a Maxwellian electron energy distribution function:

$$\frac{I(\lambda_\alpha)}{I(\lambda_\beta)}=\frac{N_{n=3}A_{32}}{N_{n=4}A_{42}}\frac{\lambda_\beta}{\lambda_\alpha}\frac{1}{F_R}=\frac{\langle\sigma v\rangle_{g\to n=3}}{\langle\sigma v\rangle_{g\to n=4}}\frac{\sum_{l<4}A_{4l}}{\sum_{i<3}A_{3i}}\frac{A_{32}}{A_{42}}\frac{\lambda_\beta}{\lambda_\alpha}\frac{1}{F_R}$$

where N represents populations of emitting levels, *n* the level quantum number, *g* the ground state, A the Einstein coefficients, $\langle\sigma v\rangle$ the excitation rate coefficients by electron impact and F_R the relative calibration factor.

Experimental results. A first set of acquisitions has been made by JAZ in the pressure range allowed by the machine operative conditions. An example of spectrum is shown in Fig. 3. In order to validate the accuracy of the results, the measurements have been repeated by JBY spectrometer. Figure 4 shows the JBY spectrum relative to H_β line (its high resolution does not allow to record H_α and H_β lines in the same spectrum). The spectral range delimited by the red lines correspond to the base width of H_β signal acquired by JAZ and clearly reveal the presence of secondary peaks due to ro-vibronic transitions of molecular hydrogen.

Elaborations of JBY spectra have been performed to understand the origin of the discrepancy observed between the two sets of data. In fact the Te values estimated from the ratio of the peak intensity of H_α and H_β lines seem to be overestimated by JAZ for all plasma parameters with respect to JBY at high resolution. A good agreement between the two spectrometers has been found repeating calculations after the integration of JBY spectra over the JAZ resolution and comparing the resulting peak values, as from the spline fitting of JBY spectra. The same results have been obtained using areas subtended by JBY lines of the high resolution spectra. For these results we can assume that information from JBY peaks, more realistic for its higher resolution, are just spread by JAZ on a larger range but these last are still valid being affected only marginally by molecular emission. A summary of all above elaboration techniques is shown in Fig 5. The dashed line represents the ideal condition in which the Te values measured by the two instruments coincide. As it can be seen, all the elaborated data are close to this ideal situation. On the same graph the JBY Te data, estimated from the peak intensities, are plotted and interpolated with a straight line of 0.749 angular coefficient. This value, assumed as calibration coefficient for JAZ instrument, indicates that Te from JAZ are overestimated by 25%. The derived coefficient will be used in the multi-chord version of the diagnostic, which will be based on an array of JAZ spectrometer for its easier layout and software interface.

A comparison with LPA has been made in different density plasmas ($3 \times 10^{10} - 7 \times 10^{10}$ cm^{-3}) using a RF power scan (250-1750 W). The results, reported in Fig. 6, show an agreement between the two diagnostics at least in their trend with respect to pressure.

It has to be noted that LPA Te measurements are always above the OES obtained value (corrected with the calculated calibration coefficient). This can be explained considering the fact that LPA performs local measurement (~ probe tip dimension) while OES integrates the measurement on the whole sightline, including part of the plasma columns where Te is well below its central value. The Abel inversion technique on the multi-chords version of the diagnostic will be used to measure Te profile, resolving the problem of signal integration.

Conclusion. A diagnostic based on Optical Emission Spectroscopy has been demonstrated to be a valid diagnostic for Te measurement in a low density laboratory plasma based on a corona model. The spectra have been acquired by a low resolution spectrometer that has the advantage of being very versatile. This choice requires a correction calibration factor that has been determined by comparison with a higher resolution spectrometer. A good agreement with Langmuir probe data has also been proved. The feasibility study successfully conducted on a single sightline will lead to the construction of a more complex multi-chord layout for the measurement of Te profiles by Abel inversion techniques.

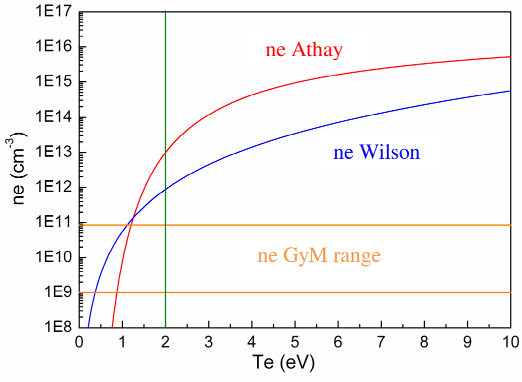

Figure 1. Criteria for the applicability of the corona model.

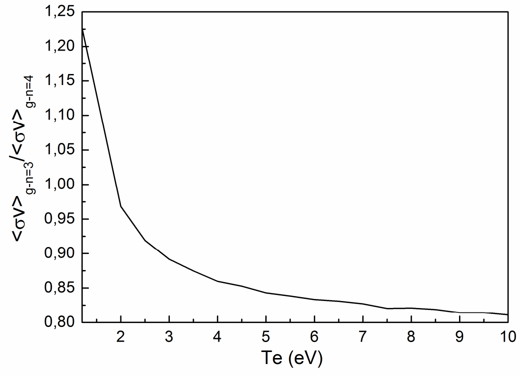

Figure 2. Ratio of the electron impact excitation rates of n = 3 and n = 4 levels.

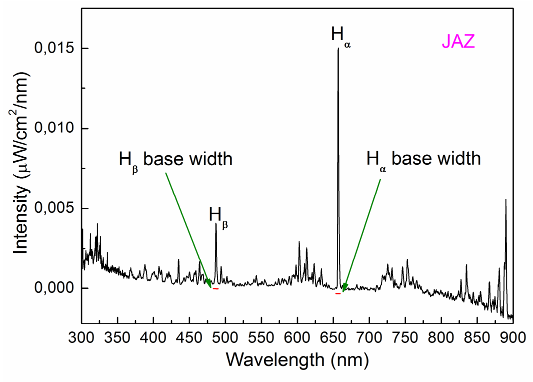

Figure 3. Example of low resolution spectrum.

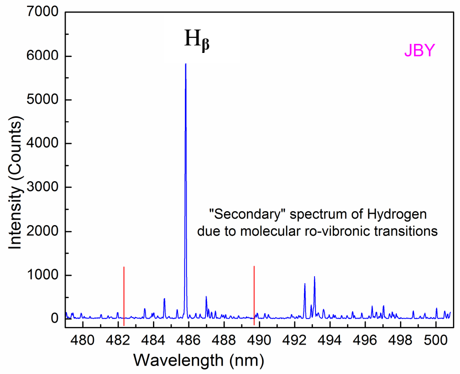

Figure 4. Example of high resolution spectrum around H_β line. The red lines delimit JAZ H_β base width.

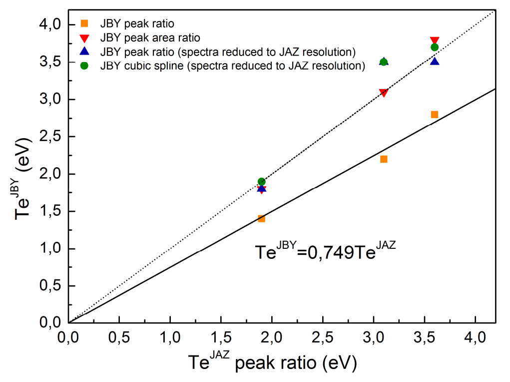

Figure 5. Comparison of Te values obtained by the two spectrometers.

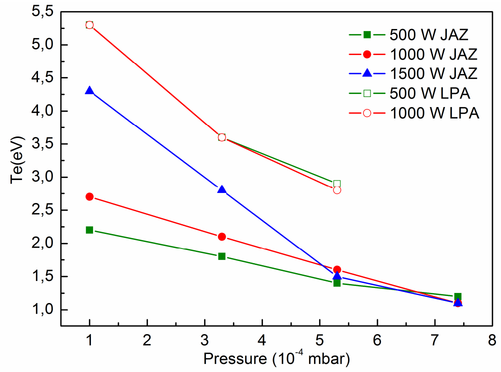

Figure 6. Comparison between JAZ and LPA results.

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