ITER plasma spectra modelling for charge exchange recombination spectroscopy

S.V. Serov[1], S.N. Tugarinov[1], M. von Hellermann[2]

[1] *Institution "Project Center ITER", Moscow, Russia*

[2] *ITER Organization, St. Paul-lez-Durance, France*

Introduction

Diagnostics complex is an important part of any modern tokamak or stellarator. Charge exchange recombination spectroscopy (CXRS) diagnostics is used to measure local values of ion temperature, impurities density and plasma rotation velocity. The first CXRS systems were developed in the late 1970s [1] and now CXRS is widely used on tokamaks. It was shown [2] that CXRS will work on ITER and it will be one of the most important diagnostics, because it would be used to measure all main plasma parameters determining the efficiency of the fusion reaction. The basic principles of CXRS are described in [3, 4].

This work presents CXRS-Edge diagnostics for ITER. The CXRS spectra modelling for ITER tokamak is considered. The main principles of spectra modelling in presence of the diagnostic neutral beam are discussed. Simulation of Spectra code, created specially for CXRS modelling is described. Spectral profiles, calculated for ITER scenario are presented. The main challenges of CXRS modelling for ITER are described. It is shown that CXRS-Edge diagnostics will allow performing an ion temperature, impurities density and rotation velocity measurements in accordance with ITER requirements.

CXRS-Edge diagnostics

ITER charge exchange spectroscopy diagnostics will consist of three systems: CXRS-Core, CXRS-Edge and CXRS-Pedestal. The first one will observe inner plasma ($0 < r/a < 0.5$), second one – outer plasma ($0.5 < r/a < 1$) and the last one will look at plasma pedestal region ($0.85 < r/a < 1$). CXRS-Edge system is being developed and manufactured in Russia by institution "Project Center ITER".

The design of the CXRS-Edge diagnostics is shown in figure 1. Diagnostic neutral beam will be injected horizontally and transversely to the toroidal magnetic field. Diagnostics will be located in the equatorial port plug and will collect light over 26 lines of sight. Light will be transmitted to the entrance slits of 9 high etendue spectrometers (HES), specially designed for this system. Each spectrometer will have three channels: blue, green and red, allowing the registration of three spectral regions simultaneously: 464–471 nm, 523–531 nm and 649–663 nm.

According to ITER requirements [5] CXRS-Edge should measure ion temperature, impurities density and rotation velocity profiles with 10–100 ms time resolution and 10–30 % accuracy. Special resolution should be 20 mm for plasma boundary ($r/a > 0.85$) and 60 mm for outer plasma ($0.5 < r/a < 0.85$). To meet this requirements measured profiles should contain enough information, that is active line should be visible over the continuum fluctuations. To measure this quantitatively Signal-to-Noise Ratio (SNR) is used. Accuracy required by ITER corresponds to SNR $\sim$ 10 [2, 6].

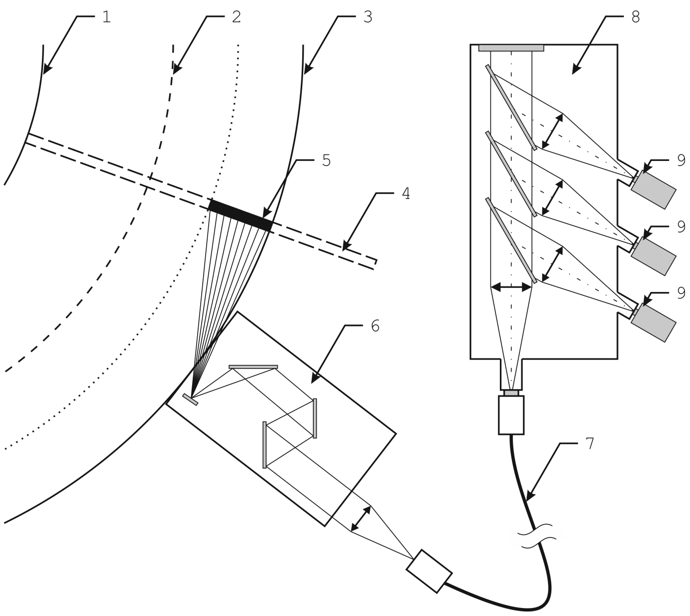

Figure 1: *CXRS-Edge system on ITER. 1 – inner plasma boundary, 2 – plasma center, 3 – outer plasma boundary, 4 – diagnostic neutral beam, 5 – light collection region, 6 – mirror labyrinth, 7 – fiber bundle, 8 – three channel spectrometer, 9 – detectors*

CXRS modelling

Modelling was carried out for different ITER scenarios, calculated using transport ASTRA code [7]. Here we will show the results only for the inductive scenario $Q = 10$, $I_p = 15$ MA, $P = 500$ MW. Concentration, temperature and velocity profiles, used for modelling, are shown in figure 2. Plasma composition was: $n_{D+T} = 0.77n_e$, $n_{He} = 0.04n_e$, $n_{Be} = 0.01n_e$, $n_C = 0.001n_e$, $n_{Ne} = 0.003n_e$. The following diagnostic neutral beam parameters were taken: $E = 100$ keV, size 0.3×0.3 m, current 36 A. Optical system, spectrometer and detector parameters were taken from the existing prototypes. Integration time was 10 ms and observation point varied from $r/a = 0.5$ to 1.0. In this article only profiles for $r/a = 0.5$ are presented, because it is the worst case and it corresponds to lowest SNR.

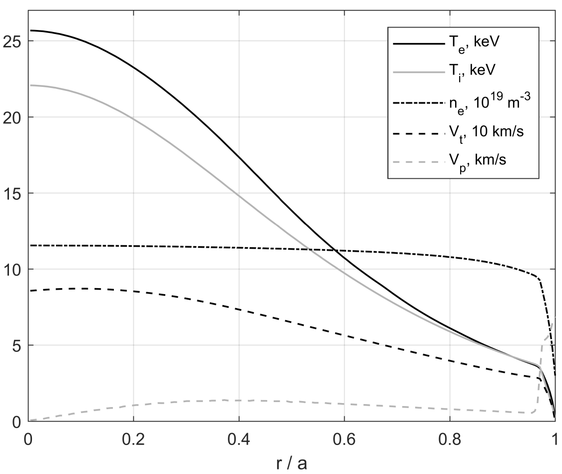

Figure 2: *Profiles, used in modelling: electron density, ion and electron temperature, toroidal and poloidal velocity*

Modelling was done using special Matlab code Simulation of Spectra [8], created by M. von Hellerman. It is designed to model CXRS for many modern tokamaks. It predicts spectrum for selected impurity, based on geometry, plasma, diagnostic beam, optical system and spectrometer parameters. It uses atomic data from ADAS database [9] to calculate diagnostic beam attenuation, active line intensity etc. Important atomic processes contributing measured line shape are taken into account: fine structure, cross-section [10, 11] and halo effect [12]. Apart from active charge exchange line (ACX) passive charge exchange (PCX) intensity is calculated and emission from not fully ionized impurities that exist in the colder plasma edge (edge lines) is taken into account.

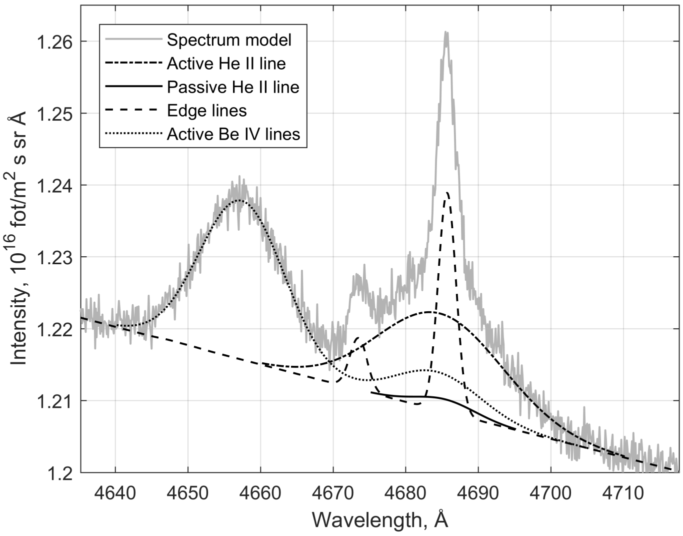

Figure 3: *Modelled spectrum for 464–471 nm region: ACX He II (4–3) 4683 Å, PCX He II 4685 Å, edge lines (He II 4685 Å, Be II 4673 Å) and ACX Be IV (6–5) and Be IV (8–6) (4658 and 4685 Å)*

Also continuum radiation is integrated along the line of sight. All these components are summarized and result spectra with its components is displayed.

Modelling results

Figures 3 and 4 show modelled spectra for 464–471 nm and 523–531 nm spectral regions. One can see that active line is blended with emission from edge lines and with PCX emission. High continuum level due to bremsstrahlung should also be noted. It has level that exceeds active signal by two orders of magnitude and this is specific for ITER compared to other operating tokamaks. For all modeled spectra SNR was $\gtrsim 10$.

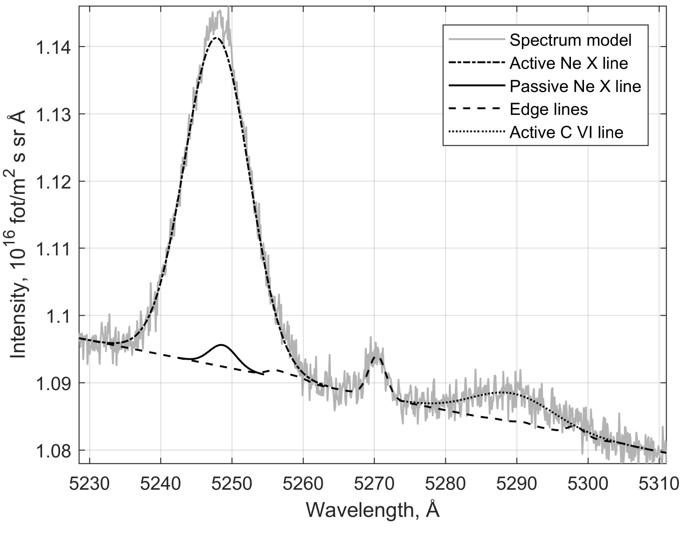

Figure 4: *Modelled spectrum for 523–531 nm region: ACX Ne X (11–10) 5248 Å, PCX Ne X 5249 Å, edge lines (Be II 5255 Å and 5270 Å, C III 5291 Å, Ne I 5298 Å) and ACX C VI (8–7) 5291 Å*

Reflected light becomes a big complication for all spectroscopic diagnostics on ITER, because ITER will have a fully metallic wall, which has a higher reflectance compared with carbon. Strong line and continuum emissions from the divertor can significantly disturb the emission coming from the main plasma. But it is not a very big complication for CXRS-Edge diagnostics, because temperatures in divertor are significantly lower than measured by CXRS and therefore reflected light influence can be eliminated, since the spectrum of the cold component is significantly narrower than the CX emission. Reflected light will only raise continuum level resulting in increase of the noise level by roughly 50 % [14].

An important question is benchmarking of Simulation of Spectra code predictions against experimental results of existing tokamak. It was done for many tokamaks, including JET and TEXTOR [8, 13]. The modelling of ACX line is in a good agreement with the experiment, but the modelling of PCX and edge lines could be inconsistent. For example for JET pulse #87404 active C VI line temperature and intensity differs from experimental data only by 15 %, but edge Be II line has two times lower temperature and intensity than the experimental values.

Conclusion

Modelling for CXRS-Edge ITER diagnostics was carried out using Simulation of Spectra code. This code was benchmarked against experimental results on existing tokamaks and its predictions are reasonably close to the experimental spectra. This means that it could be used to simulate workable ITER CXRS spectra, that could be used to develop data processing means. Modelling was done for several ITER scenarios for three spectral regions. It shows that CXRS-Edge will allow measuring plasma parameters for $0.5 < r/a < 1$ with required accuracy and time resolution.

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