Measurements of impurities concentrations using modernized CXRS diagnostics at T-10

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Active spectroscopic diagnostics (CXRS) is developed at T-10 tokamak for measurements of the plasma ion temperature and impurities concentrations [1,2] . Modernized scheme of the diagnostics includes 3 High Etendue Spectrometers (HES) as shown in figure 1. Upgraded design allows providing simultaneous measurements of beam H_α line and 2 impurities CXRS spectra. Light from two collecting systems is transmitted by optical fibers to spectroscopy control room. Each system collects light from 9 lines of sight, uniformly distributed from -0,3a_L to a_L (a_L=30 cm, rail limiter radius). Registration system includes 3 spectrometers and 3 scientific cameras: two EMCCD PhotonMAX 512B and PIXIS 512B. Spectrometers based on Echelle gratings are marked as HES1 and HES2, spectrometer with holographic grating for 529 nm is marked as HES3. HES1 and HES3 spectrometers are coupled in one box as shown on figure 2. Light of 529±10 nm diffracts on the first grating with ~50% efficiency, while the rest of light outside its operational wavelengths range passes through the holographic grating with ~0.8-0.9 transmission coefficient, allowing to measure spectra of another CXRS line or H_α beam line, depending on experiment requirements. Combined spectrometer allows performing precise concentration profiles measurements in case of simultaneous impurity CXRS line and beam H_α line spectra, because in that case the most of uncertainties and possible measurements errors are canceled [3].

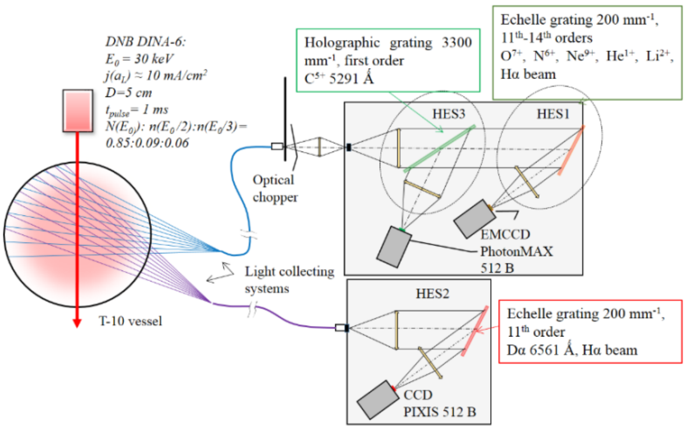

Fig 1. Scheme of CXRS measurements at T-10

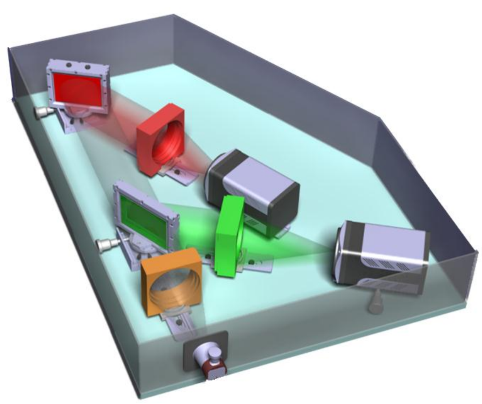

Fig 2. Combined spectrometer HES13

Spectrometer with 3 holographic gratings for 468, 529 and 656 nm is a prototype developed for CXRS diagnostics of ITER edge plasma ($\rho \geq 0.5$). Chosen scheme and used elements have shown very promising results during tests at T-10 machine.

Profile measurements of plasma intrinsic impurities (C, N, O) and injected impurities (He, Li, Ne) are provided using the modernized diagnostic scheme in various OH and ECRH discharges. It is found that in T-10 wall conditions in operational regimes there are similar high values of carbon and oxygen concentrations (1.5–3% of n_e) without any significant nitrogen concentration. Therefore, in 2014 T-10 experimental campaign the combined spectrometer was used for measurements of two main light impurities, oxygen and carbon, while spectrometer HES2 was used for measurements of beam H_α line. This approach provides reliable concentrations measurements, but it requires accurate relative calibrations using beam in gas emission and absolute calibrations of all spectrometers.

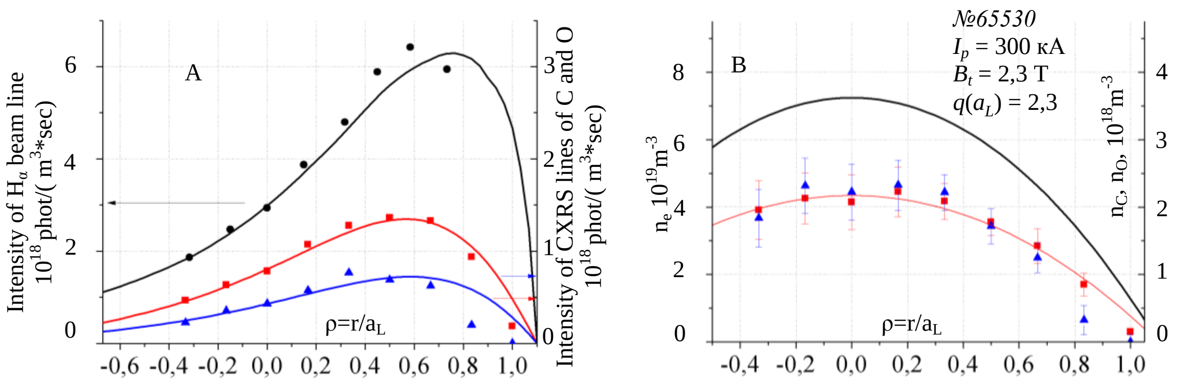

Fig 3. A - distributions of intensities of main energy H_α beam line and CXRS lines of carbon and oxygen. ● –H_α beam, ■ – CXRS C^{5+}, ▲ – CXRS O^{7+}, dots – measured data, curves – numerical calculation. B – measured carbon and oxygen profiles, black line – $n_e(r)$, red line – normalized $n_e(r)$

For verification of CXRS data, measurements in high plasma current OH discharge are shown. This kind of discharges at T-10 is characterized by measured Z_{eff}=const(r) profile, thus impurities distributions are similar to n_e profile. Figure 3A shows intensities distributions of main energy H_α beam line and CXRS lines of C and O in ohmic discharge with I_p=300 kA and $\bar{n}_e = 4{,}8\cdot 10^{19}$ m^{-3}. Dots correspond to experimental data, curves are results of calculations with ADAS [4] data. Measured concentration profiles of carbon and oxygen nuclei (Fig. 3B) produce effective ion charge profile that is in good agreement with independent measurements of $Z_{eff}(r)$ via bremsstrahlung. The deviation of the C and O nuclei concentrations from the calculated line at the plasma edge (ρ>0.8) can be caused by the charge exchange with main gas atoms which was not taken into account in the numerical model.

Impurities behavior in OH plasma

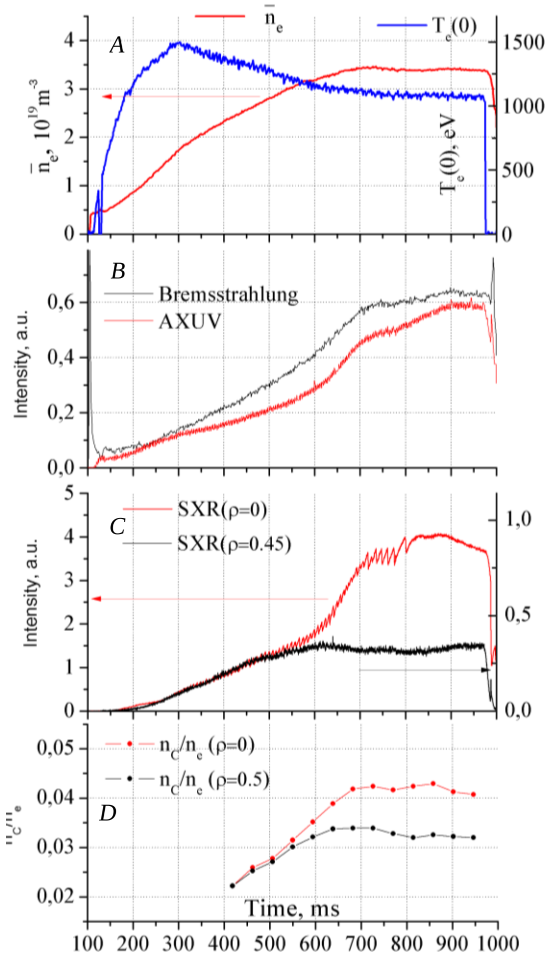

Fig 4. Plasma parameters in OH discharge at plasma current 180 kA with termination of saw-tooth activity.

Measurements with the modernized CXRS system allow revealing a strong dependence of light impurities behavior at OH discharges on plasma current and electron density. In high plasma current case measured impurity profiles is similar to $n_e(r)$, indicating the dominance of the anomalous transport, but at lower plasma current and higher electron density the impurity accumulation is observed that can be caused by the increase of neoclassical processes against the anomalous transport. This accumulation can lead to a termination of the sawtooth activity without any external action on plasma (see fig.4C). The accumulation of impurities is confirmed by bremsstrahlung measurements of Z_{eff}, and also by AXUV and SXR radiation dynamics. At the first stage of the discharge the total impurity concentration increases (fig.4, t<600ms), but impurity profiles stay similar to $n_e(r)$. Then the process of impurities peaking is observed that can lead to the current profile flattening and the saw-tooth stabilization. Peaking of impurities in contaminated plasma indicates strong influence of Z_{eff} value on ratio of neoclassical and anomalous transport.

Impurities behavior in ECRH plasma

Light impurities removal from plasma center with ECRH is investigated on T-10 using the CXRS diagnostics. Figure 5 shows n_e and impurities profiles in OH and ECRH discharges with low plasma current (I_p=180 kA). At OH stage carbon and oxygen are more peaked than electron density n_e. After central ECRH switch-on, concentrations of C and O drop by a factor of ~2–2.5 and radial profiles of impurities become similar to $n_e(r)$ within the error limits. Observed effect at ECRH stage is related to the initial neoclassical accumulation of impurities in the OH plasma that is disturbed by the ECRH impact. Similar effect was observed in other machines and the closest result was obtained at TCV [5]. The impurity transport study in T-10 in OH and ECRH regimes is described in [2].

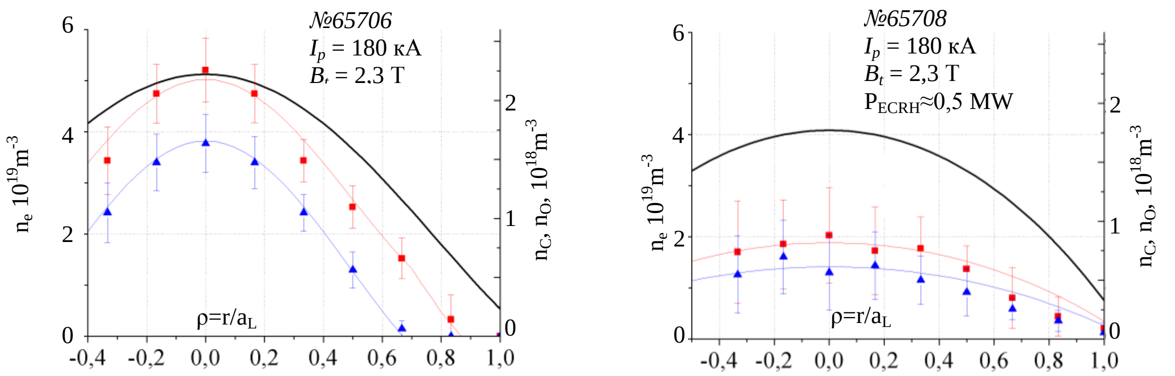

Fig 5. Electron (——), C(■) and O(▲) density profiles in OH (left) and ECRH (right) discharges at Ip=180 kA.

Efficiency of impurities removal increases with higher plasma density, Z_{eff} value and with lower plasma current in OH stage and with higher heating power in ECRH stage. In discharges with the highest $n_e \cdot Z_{eff}/I_p$ ratio the nuclei impuritiy concentration can decrease up to 3 times in ECRH regime comparing to OH values. In conditions of the sufficient change of the transport from the neoclassical one in OH stage to the strong anomalous in ECRH stage, there is a possibility for the determination of impurities anomalous transport coefficients D and V in ECRH stage using light impurities nuclei dynamics measured by CXRS and dynamics of impurity sources. Despite the fact that confinement of impurities in central zone with ECRH significantly decreases indicating increase of anomalous impurity transport, measured density turbulence at radii ρ>0.4 decreases with ECRH relatively to OH stage [6]. Study of relation of plasma turbulence and impurities transport is the subject of further investigation at T-10.

Acknowledgements

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References

1. V.A. Krupin et al. – Plasma Physics Reports, 2013, Volume 39, 8, pp 632-643
2. L.A. Klyuchnikov et al. – IAEA FEC 2014, EX/P1-44
3. Bespamyatnov I.O. et al. – Review of Scientific Instruments 2010, vol. 81, 10D709.
4. The Atomic Data and Analysis Structure (ADAS) http://www.adas.ac.uk/
5. Emiliano Fable, – “Experimental and Theoretical Study of Particle Transport in the TCV Tokamak”, 2009
6. V. Vershkov et al, – Nucl. Fusion 55 (2015) 063014.