# Measurements of ion temperature of plasma via CXRS at T-10

A.G. Barsukov[1], K.Yu. Vukolov[1], A.Yu. Dnestrovskij[1], L.A. Klyuchnikov[1], K.V. Korobov[1], V.A. Krupin[1], N.N. Naumenko[2], A.R. Nemec[1], S.N. Tugarinov[1]

[1]*National Research Centre "Kurchatov Institute", Moscow, Russia*

[2]*IPh NASB, Minsk, BR*

## Introduction

CXRS diagnostics is intended for measurements of the main plasma parameters, such as ion temperature [1,2], rotation velocities, densities of operational gas ions and impurities. This diagnostics is widely used at all modern tokamaks.

CXRS diagnostics for ion temperature profile measurements was installed at T-10 on the base of the DINA-6 diagnostic beam. Diagnostics was developed for modelling of the CXRS diagnostics for ITER. Spectroscopic equipment and methodic of the CXRS diagnostics of ITER are being tested in the diagnostic scheme at T-10.

## Experimental set-up

The base element of the CXRS diagnostic of T-10 is the diagnostic beam DINA-6 with the beam energy $E_0$=30 keV and neutral current density $j(a_{Lim})$=10 mA/cm$^2$, pulse duration is 1 ms. We can have up to 10 beam pulses with a period of ~40 ms per plasma discharge. Concentration of main component with energy $E_0$ is dominant, the proportion among concentrations of beam components at plasma edge is $N_{E0}:N_{E0/2}:N_{E0/3}$ = 82:11:7.

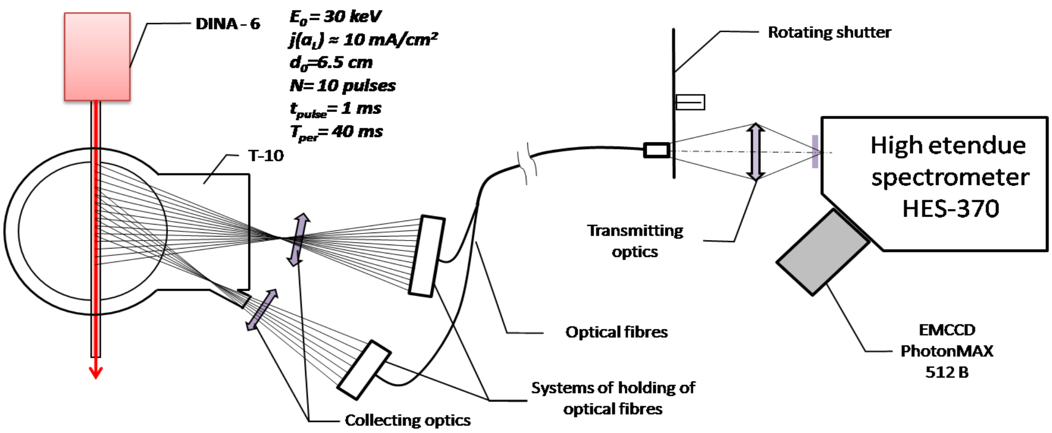


Figure 1. Scheme of CXRS measurements at T-10.

For CXRS measurements we use two poloidal light collecting systems. Optic axis of the first one intersect the beam at an angle of ~30° to normal of the beam direction, it is mainly used for measurements of the CXRS $D_\alpha$ and the beam $H_\alpha$ lines. The second light collecting system, placed in equatorial plane, is used mainly for measurements of ion temperature using the CXRS lines of impurities.

HES-370 (“High Etendue Spectrometer”) is used for CXRS measurements at T-10.
This spectrometer with echelle grating works in high orders of dispersion. Main parameters of the spectrometer are:

- Aperture angle $\alpha \approx 1/3$;
- Slit height $H_{slit}=30\ mm$;
- Dispersion $D=3\div5$ Å/mm;
- Transmission $K=30$ %;
- Astigmatism ~10 mcm;
- Spectral resolution 0.15 Å;
- Band-pass filters with K>85% and OD~$10^4$

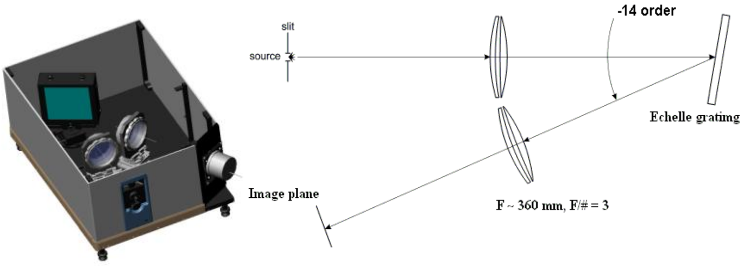

Figure 2 High Etendue Spectrometer HES-370

EMCCD camera “PhotonMax-512B” registries CXRS spectra from 5 selected space points. Mechanical rotating shutter is introduced to the registration scheme for removal of the effect of vertical blur of spectral signal during readout. The shutter periodically closes camera from light for 3 ms readout time and opens for 1 ms exposition. Every turn of the shutter generates 1 synchroimpulse for a beam pulse launching and 10 synchroimpulses for a camera exposition launching. Such organization of light collection allows us to use the time difference scheme of measurements for subtraction of active component from active+passive spectra. As a result we obtain 10 active spectra, initiated by the neutral beam during 400 ms of discharge time. Thus, 5 space points of ion temperature profile can be measured 10 times per 1 discharge of T-10.

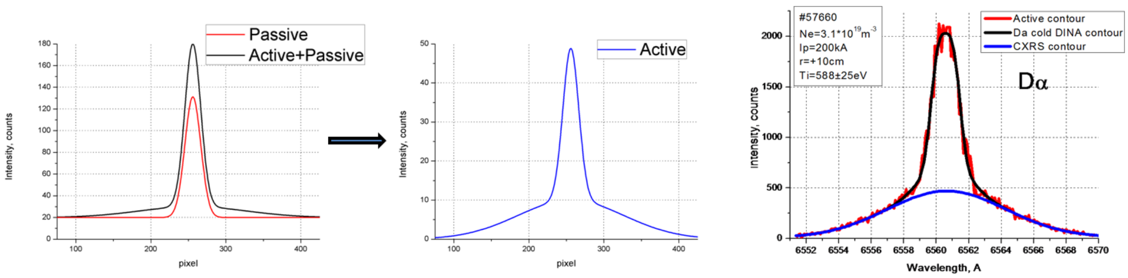


Figure 3 Difference scheme of measurements in the region of the $D_\alpha$ line.
a) Initial passive and active+passive spectra b) Obtained active spectra c) Experimental active spectra and gaussian fiting of hot (from the zone of intersection of the beam and observation chord) and cold components initiated by the hydrogen beam (from plasma edge).

Active $D_\alpha$ line spectre contains a cold contour in addition to a CXRS contour. A cold contour appears because hydrogen beam catches vessel walls and knocks deuterium atoms that locally enter plasma and radiate additional spectral signal that interferes with useful CXRS signal. But as one can see in fig 3c we have sufficiently high SNR for reliable measurements.

**The "halo" effect, experiment and modelling**

Ion temperature profiles of T-10 plasma were measured via CXRS diagnostic in shots with various current and density values, with different operational gases and using different CXRS lines ($D_\alpha$ (6561 Å), $He^{+1}$ (4686 Å) $Li^{+2}$ (5167 Å) and $C^{+5}$ (5291 Å)). The systematic discrepancy was found by detailed comparison of ion temperature profiles, measured by the $D_\alpha$ 6561 A and the $C^{+5}$ 5291 A lines in deuterium plasma. Ion temperature profile measured by the $D_\alpha$ line is lower in the plasma center and is broader than profile, measured by the carbon line (see fig. 4). This discrepancy can be explained by the "halo" effect [2], which leads to worsening of spatial resolution of CXRS measurements and to deformation of measured ion temperature profile.

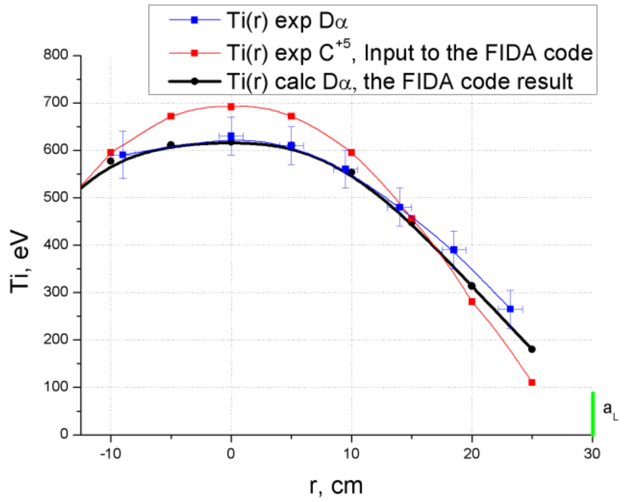


Figure 4 Experimental ion temperature profiles from the $D_\alpha$ line (blue), from the $C^{+5}$ line (red) and Ti profile from the calculated $D_\alpha$ line (black). $D_\alpha$ line calculated in the FIDA code, experimental $C^{+5}$ Ti profile is the input to the FIDA code.

Halo atoms from zones with high temperature are mixed with cold halo atoms from plasma edge and also, lines of sight pass through zones with various halo temperatures. Thereby our spectral signal from l.o.s. is a mix of gaussians with various temperatures, which leads to flattering and broadening of ion temperature profile.

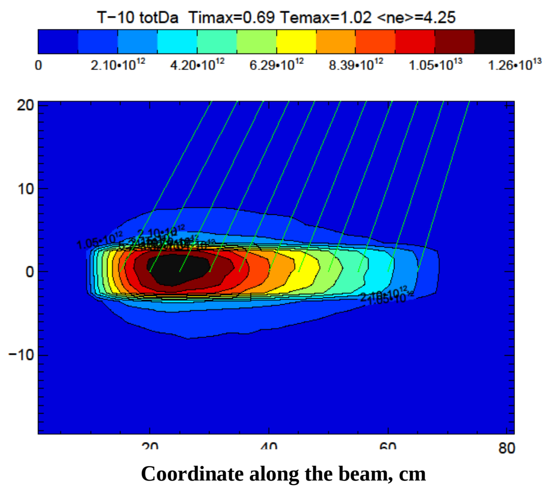


Figure 5 The $D_\alpha$ line signal initiated by the diagnostic beam in T-10 plasma. Calculation with the FIDA code. X – coordinate along the diagnostic beam, Y – coordinate across the diagnostic beam. Observations chords are shown by the sloping lines.

Direct measurements of intensities of the CXRS lines of deuterium and carbon inside and outside of the diagnostic beam area have confirmed the existence of the "halo" effect for the $D_\alpha$ line and showed the absence of deuterium halo influence for the $C^{+5}$ line.

The model in the Monte-Carlo code FIDA [4] was created to restore the ion temperature profiles measured using the $D_\alpha$ line signal. The discrepancy between ion temperature profiles measured using the $D_\alpha$ and the $C^{+5}$ lines is described as it is shown in fig 4. The good coincidence between the measured ion temperature profile using the $D_\alpha$ line and the model profile is clearly seen. $D_\alpha$ line intensity distribution along and across the beam calculated by the FIDA code is shown in Fig.5.

**Conclusions**

High performance of all spectral equipment allows us to provide reliable measurements of ion temperature profiles in steady state of a discharge using the CXRS lines of plasma impurities and the line of the operational gas (Dα 6561A) in spite of low neutral beam current and short beam pulse duration.

Beam current will be increased and parasite signals will be removed by modernization of the diagnostic beam in next experimental campaigns at T-10. Thereby more reliable measurements of ion temperature will be possible in the nearest time.

The discrepancy of ion temperature profiles measured using the $D_\alpha$ and the $C^{+5}$ lines can be explained by the "halo" effect. It is planned to use spatial difference scheme of measurements of CXRS spectra to reduce influence of the "halo" effect for ion temperature measurements. New set of observation chords will be directed parallel to existing chords out of the diagnostic beam zone for subtracting of halo+passive spectre from CXRS+halo+passive spectre. In such scheme of measurements in case of high statistics of the $D_\alpha$ line measurements we hope to obtain ion temperature profile almost the same as a profile, measured by the $C^{+5}$ line due to much lower contribution of the "halo" effect into a difference signal.

Also system of peripheral ion temperature measurements by Doppler broadening of the $C^{+5}$ line is planned to be installed in the range $r=0.75-0.9a_L$. This is important because measured ion temperature on the plasma edge has the highest discrepancy due to the "halo" effect.

Work was carried out by ITER RF Agency №H.4k.52.90.11.1095 and was supported by "Rosnauka" 12.05.2011 №16.518.11.7004 and "Rosatom" 28.02.2011 № H.4f.45.90.11.1021

**References**

[1] E.L.Berezovskij e.a. Zh. Tekh. Fiz., Pis'ma 8 (1982) 1382

[2] E.L.Berezovskij e.a. Nuclear Fusion, Vol.25, No.10 (1985) 1495

[3] RC Isler. Physica Scripta, 35(5):650_661, 1987.

[4] W.W. Heidbrink, et al., A Code that Simulates Fast-Ion Dα and Neutral Particle Measurements, Commun. Comput. Phys., Vol. 10, No. 3, pp. 716-741A