Study of ion heat transport in NBI experiments on the Globus-M spherical tokamak

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This work presents results of ion heat transport study in the Globus-M spherical tokamak[1] (major radius R = 0.36 m, minor radius a = 0.24 m, aspect ratio - 1.5, vertical elongation k ~ 1.9, toroidal magnetic field B_{tor} ~ 0.4 T) plasma confined in a divertor configuration with an active lower point. Experiments were carried out at various plasma currents I_p = 115 – 200 kA and average electron density $\langle n_e \rangle \sim$ 2-5×10^{19} m^{-3}. The deuterium neutral beam with a power of 440 kW and energy of the particles - 23-28 keV was co-injected in deuterium plasma. Typical temperature values were in the range of 250-450 eV for ions, and 400 – 1000 eV for electrons. A comparison of experimental measured ion temperature profiles and results of modeling by transport code ASTRA [2] was performed to study the ion heat transport.

The ion temperature profiles were measured by CXRS (Charge eXchange Recombination Spectroscopy) [3] and NPA (Neutral Particle Analyzer) [4] diagnostics. Fig. 1 shows the experimental setup at Globus-M tokamak. Two viewing chords of CXRS diagnostics intersect the NBI axis at R = 42 cm and R = 47 cm, NPA ACORD-12 at R = 32 cm. Shape of CVI (5290.5 Å) spectral line was measured by CXRS diagnostics in NBI heated discharges to determine ion temperature. The raw measured spectra for each moment of time were averaged in a series of 5-6 discharges and the result was approximated as a sum of the background (Bremsstrahlung radiation) and two Gaussians: a «passive» component and an

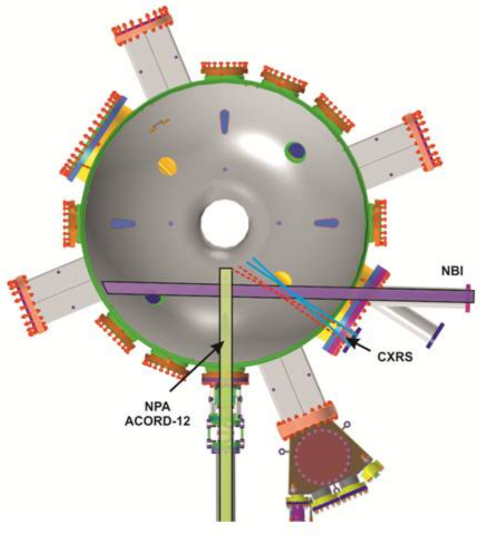

Figure 1 *Experimental setup. Solid line shows the CXRS viewing chord which intersects the NBI axis at R = 47 cm, dashed line at R = 42 cm; NPA ACORD-12 observation chord intersects the NBI axis at R= 32 cm.*

«active» component. «Active» component describes the emission caused by charge exchange reaction of impurity nuclei and neutral particles of heating beam in points of the intersection of CXRS and NBI (42 ±2.4 cm and 47±2.7 cm). «Passive» component is caused by emission of C^{5+} ion that exists in plasma in particular range of temperatures below ionization potential. According to the collisional-radiative model the distribution of C^{5+} ion is quite narrow and concentrates in the temperature range about 80-120 eV. Such conditions in Globus-M tokamak plasma corresponds the LCFS vicinity. Therefore «passive» component gives the local value of ion temperature at the plasma edge and can be fitted by one Gaussian. Fig. 2 shows that the experimental signal is fitted by assuming approximation quite well.

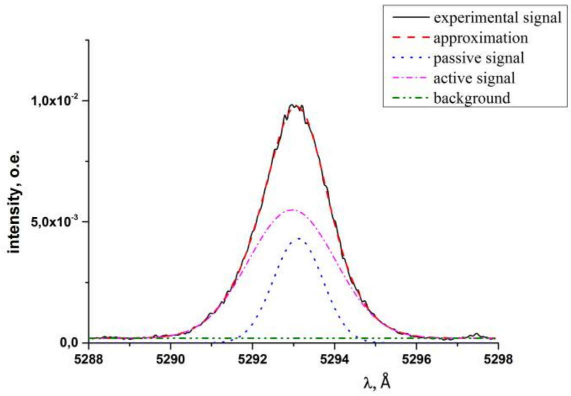

Figure 2 *Approximation of the averaged experimental signal by sum of two Gaussians («passive» and «active» components) and background.*

The neutral beam gives the main contribution into NPA signal during NBI pulse and therefore measured values of ion temperature can be treated as local (at R = 32 cm). The Figure 3 shows the data of CXRS and NPA diagnostics in one of the investigated regime (with I_P = 200 kA). The results do not contradict each other and the temporal variations of ion temperature are in a sufficiently good agreement. The values of the ion temperature were 250-370 eV and the increasing of ion temperature after NBI start is noticeable (Fig. 3). Electron and ion temperature profiles measured during NBI pulse are shown in Fing.4. Ion temperature profile is obtained by combining the data of CXRS «passive» and «active» components and NPA diagnostics. T_e profiles were measured by Thomson scattering diagnostics [5,6]. The electron temperature decreases during the time after the NBI start what can be explained by electron density rising (Fig. 5). By the end of the discharge the values of ion and electron temperatures were close to each other and the profiles had the similar shape.

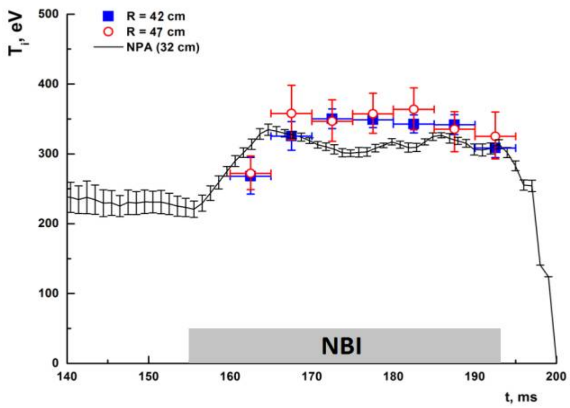

Figure 3 *Comparison of ion temperature values measured with the CXRS and NPA diagnostics in a regime with the plasma current I = 200 kA.*

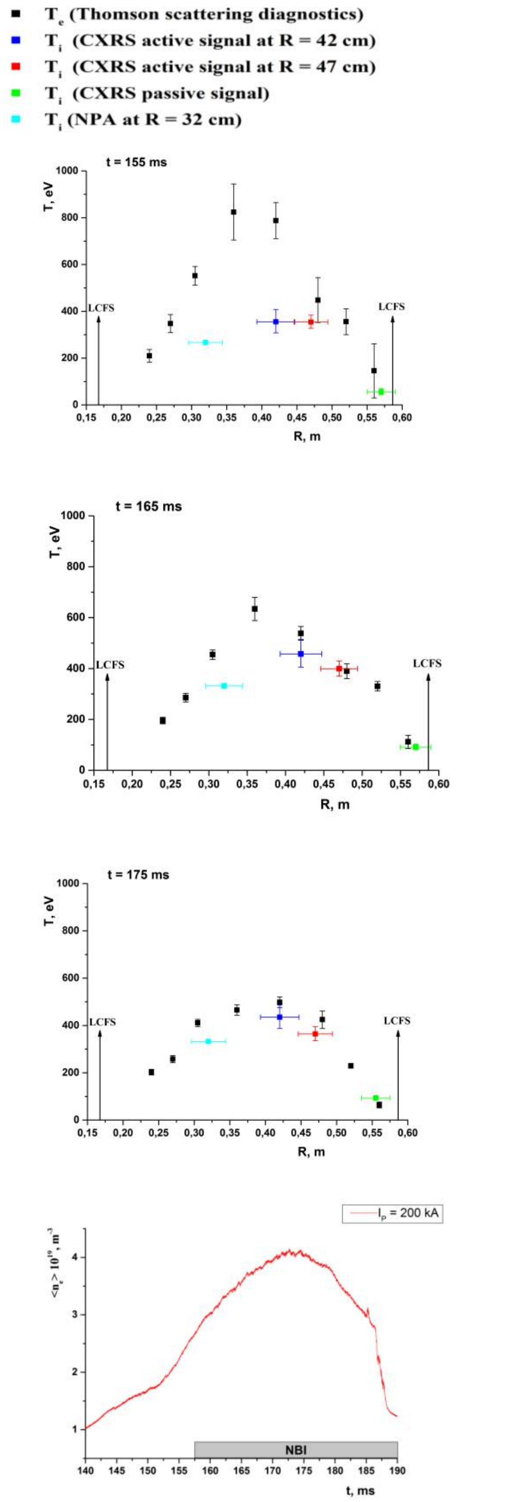

Figure 4 *Ion, electron profiles and average electron density measured in a regime with plasma current I = 200 kA. Vertical arrows indicate the separatrix position.*

Experimental data was processed with ASTRA code. The steady state phase of discharges at t = 175 ms was investigated. Simulations were performed in the framework of a model described below. The electron temperature and density profiles were experimental, while ion energy balance equation and equation for poloidal flux were solved. The geometry of the last closed flux surface was determined by the EFIT code. The plasma effective charge (Z_{eff}) was constant on the poloidal radius and selected so that the calculated plasma voltage would coincide with the measured value. The carbon was assumed as a single impurity. Neoclassical conductivity and ion heat conductivity were calculated using NCLASS [7]. NPA measurements and fast ion modeling additionally provides some data on fast ions confinement efficiency that is quite necessary to estimate the absorbed beam power [8]. The boundary condition for neutral atom density was varied to obtain the experimental value of charge exchange losses of beam particles. Direct losses of beam particles were taken into account by introducing a corrected factor for input NBI power. The overall NBI power losses for investigated discharges (deuterium plasma and deuterium neutral beam injection) were about 90 % and the rest of beam power was absorbed by electrons and ions in almost equal portions. The NBI power absorbed by ions was larger then the electron-ion heat exchange power what lead to increasing of ion temperature after NBI start (fig. 3). The electron portion of absorbed beam power was significantly smaller of the ohmic heating power and did not provide a significant increase in the electron temperature in investigated discharges.

The Fig 5 represents the results of modeling and experimentally measured ion temperature profiles for two of the investigated regimes. The neoclassical transport coefficients calculated by NCLASS are shown on Fig. 6. Comparison of experimental and modeling results demonstrates that the ion heat diffusivity is well described by the neoclassical transport coefficients in the low-aspect ratio high elongated plasma. These results are in agreement with earliest results on Globus-M tokamak [9, 10]. The calculated values of total storage thermal energy are in a good agreement with the results of diamagnetic measurements.

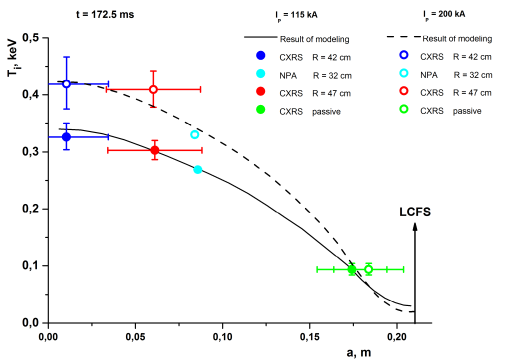

Figure 5 Comparison of modeling and experimental measured ion temperature profiles for regimes with plasma current I = 200 kA and I=115 kA.

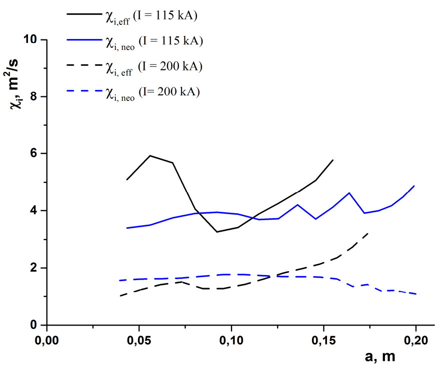

Figure 6 *Experimental ion heat diffusion coefficient (χ_{eff}) and numerically calculated neoclassical coefficient (χ_{neo}).*

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