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Study of the Beam - Plasma Interaction in the Globus-M Spherical Tokamak

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Introduction

This paper describes effects of neutral beam injection (NBI) into the spherical tokamak Globus-M [1,2]. First NBI experiments [3] demonstrated significant, by a factor of 3, increase of the ion temperature in the plasma bulk at moderate values of the plasma average density. The neutral beam heating experiment was continued in 2004 – 2005 campaign with the NB power comparable with the Ohmic one. The experiments were performed in extended range of the plasma densities and beam energies. The target plasma had following parameters: toroidal magnetic field $B_0 = 0.4$ T; plasma major radius R = 0.33–0.35 m; minor radius a = 0.22–0.23 m; vertical elongation k = 1.5–1.8. New experimental data were obtained by means of improved diagnostics (Thomson scattering, magnetic measurement reconstruction, etc.). The neutral beam was co-injected tangentially to a circumference of the radius R_s = 30 cm. The typical output power varied in the range of 0.3 to 0.7 MW and depended on the beam energy. The injector construction made possible to change the beam energy step by step in the range of 20–30 keV. The experimental equipment layout is shown in fig. 1.

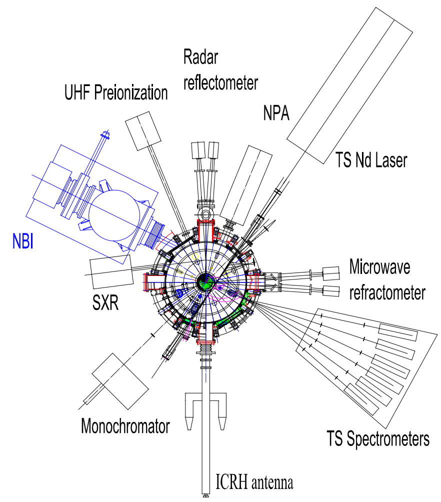

FIGURE 1. NBI layout on Globus-M.

Experimental results

Initially we compared the efficiency of plasma heating by means of hydrogen and deuterium beams with identical energy and power during one experimental day. The effect of ion heating appeared to be approximately the same in both experiments (see fig.2). Some difference (slightly larger increase of the deuterium temperature in the case of deuterium beam heating) is in agreement with ASTRA code simulation and caused by the difference in the beam particle velocity at the same energy. Only the deuterium beam was used in further experiments. Investigation of the beam power absorption was carried in the range of the average plasma densities 1–3× 10^{19} m^{-3} and currents 0.18–0.2 MA, where the ion heating is more pronounced. The energy of the injected particles varied from 20 to 30 keV. The experiments revealed the beam absorption efficiency increases with the plasma density increase. On the other hand the maximum effect of ion heating was achieved for the beam energy of 22–25 keV in the investigated density range. As shown in fig. 3, all experimental data is in accordance with numerical simulation. The spectra of CX atoms in the energy range 0–22.5 keV are shown in fig. 4. At the thermal energies (0–2 keV) the spectra for both NBI heated shot and reference OH shot are shown. At the suprathermal energies (above 4 keV) a slowing down spectrum of beam deuterons is shown. It is significant that the CX fluxes were measured in the perpendicular direction, while the beam was injected tangencially. Therefore the slowing down spectrum represents the beam particles, scattered at significant angles (~ 90 deg). Above so-called critical energy E_{cr} ~ 12 keV, where the electron drag predominates, the

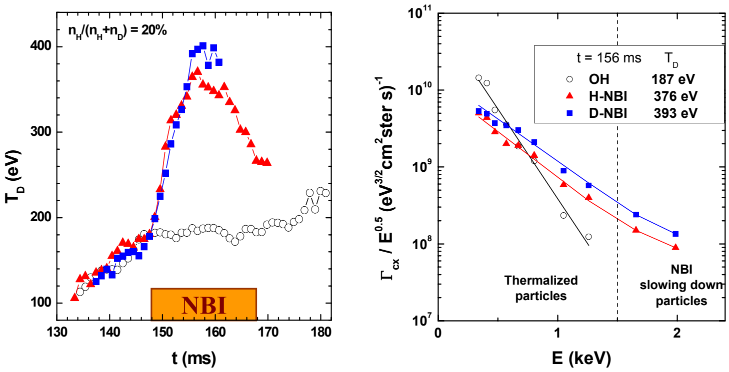

FIGURE 2. Comparison of hydrogen and deuterium beam injection. Ion temperature time evolution (left), charge-exchange deuterium energy spectra (right).
P_{NB} = 0.6 MW, E_{NB} = 30 keV, Ip = 0.15-0.16 MA.

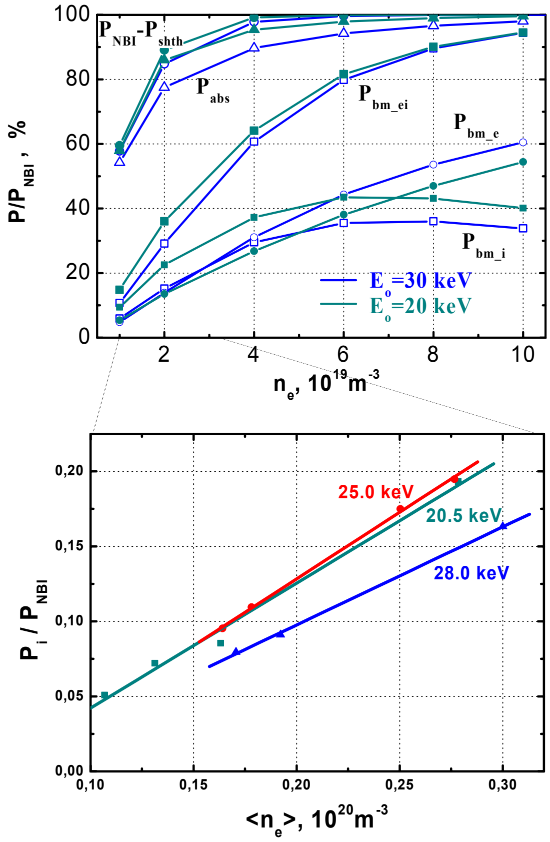

FIGURE 3. Deuterium beam power absorption. ASTRA code simulation (top), experimental data (bottom).

pitch angle scattering is not sufficient. As the result the low intensity of CX flux in the energy range 12-22.5 keV was measured. Below E_{cr} the pitch angle scattering becomes appreciable due to collisions with plasma ions. This explains the higher level of CX flux observed in the energy range of 0–12 keV. Also the slowing down spectrum below E_{cr} shows the good correlation with the general dependence $E^{1/2}\times(E^{3/2}+E_{cr}^{3/2})^{-1}$, obtained on the assumption of negligible particle losses [4]. This indicates that the process of beam ion slowing down is well described by classical Coulomb scattering theory and that the particle losses in the energy range 0–12 keV are insignificant.

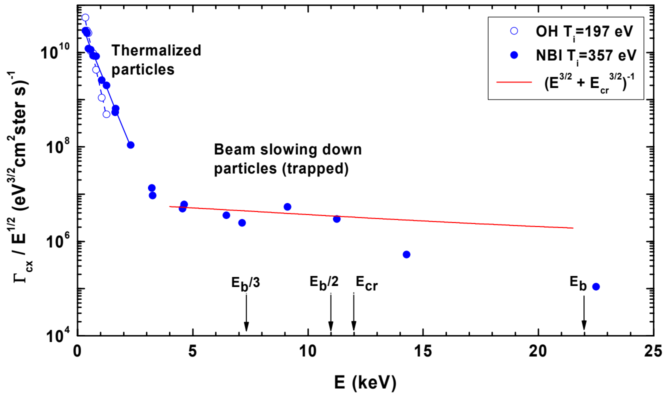

FIGURE 4. Energy spectra of charge-exchange neutrals emitted from plasma during NBI. E_{NB} = 22 keV.

In previous campaigns we could not achieved any significant effect of NBI in plasma temperature at higher values of plasma average density. In the described experiment more careful vacuum vessel conditioning as well as the improvement of the plasma position control made possible to extend the average density range up to 7×10^{19} m^{-3}. The optimization of the NBI pulse start point was made in 130–150 ms time range (plasma current begins at 113 ms). The highest heating efficiency was achieved in shorts with early beam injection (135 ms) at the plasma current range of 230–250 kA. Time evolution for some plasma parameters is shown in fig. 5. The input neutral beam power was about

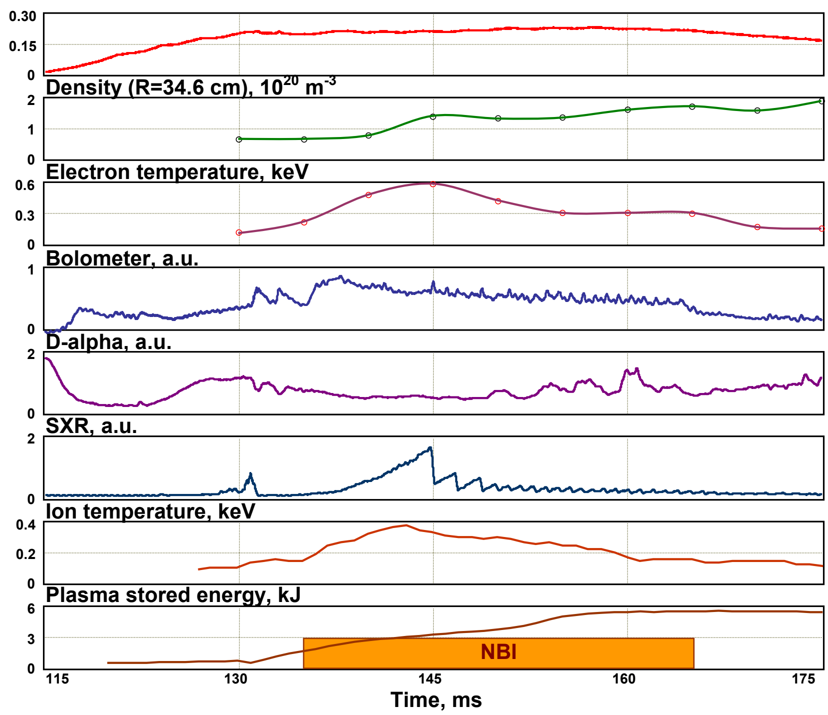

FIGURE 5. Time evolution of plasma parameters in shot #13731. P_{NB} = 0.55 MW, E_{NB} = 28 keV

0.55 MW, which is close to the Ohmic power. Electron temperature and density were measured in five spatial points along minor radius by means of Thomson scattering. Visible increase of the central electron temperature was recoded in the beginning of injection. The intensive density rise caused the subsequent electron cooling. The ion temperature measured by NPA exhibits similar behavior. It should be note that the central electron density reached a very high value of 2×10^{20} m^{-3}. In this shot the stored plasma energy approached 6 kJ.

Discussion and conclusions

The performed experimental results lie in well conformity with the predictions provided by ASTRA code simulation. For low density regimes the ion heating is mainly observed. Lower beam energy heating is more effective. The beam particles undergo classical Coulomb scattering and slowing down. The beam ion losses are negligible in the energy range 0–12 keV. The part of the NBI power absorbed by electrons is relatively low. Visible electron heating effect becomes apparent for the average densities higher than $5–6\times 10^{19}$ m^{-3}. In this case about 40% of the beam power is transmitted to electrons. In current experiment it reaches value ~0.2 MW, which is twice lower than Ohmic power.

Several novel results were obtained in last campaign. Effective electron heating has been observed in the Globus-M for the first time during NB injection. Very high density about 2×10^{20} m^{-3} has been achieved with assistance of neutral beam at low magnetic field ~0.4 T.

In further experiments it is scheduled to double input NB power. Also the study of the injection angle influence is proposed.

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