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First experiments on NBI in the TUMAN-3M tokamak

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Introduction

Neutral Beam Injection in the TUMAN-3M is aimed on increasing the experimental resources of the tokamak [1]. In particular, the *L-H* transition in presence of auxiliary heating will be investigated. In combination with Heavy Ion Beam Probe diagnostic [2] the NBI heating is expected to provide important data on effects of plasma rotation and radial electric field on *L-H* transition physics. Study of the circular plasma stability at high β is planned as well. Setup of the experiments is chosen to provide effective beam absorption and toroidal momentum input: tangential injection directed on the inner mid-radius point [3]. The NBI system consists of injector unit used in T-11 experiments [4] and newly built power supplies and data acquisition. Tests of the system have shown reliable operation at ion source current up to 30 A, beam energy 28 keV with 20 ms pulse duration. These parameters allowed estimation of maximum beam power P_{NBI} at the level of 500 kW. Paper presents results of the first experiments on NBI heating of TUMAN-3M plasma.

Description of experiments

First experiments have been performed in co-injection geometry with E=22 keV deuterium neutral beam and P_{NBI}=330 kW. Target plasma parameters were as follows: R=0.53 m, a=0.23 m, B_T=0.8 T, I_p=130 kA, $\bar{n}$=(1.3-3.0)$\cdot 10^{19}$ m^{-3}, $T_e(0)$ <0.6 keV, $T_i(0)$ <0.2 keV. Main difficulty of the first experiments was substantial impurity influx during NBI pulse. In order to reduce density increase during NBI the working gas puff has been switched off at the beginning of heating. Nevertheless, $\bar{n}$ increased by a factor of ~ 1.8 up to $3\cdot 10^{19}$ m^{-3}, see Fig.1. Total amount of injected particles was $0.28\cdot 10^{19}$. With this quantity average density should increase by $0.5\cdot 10^{19}$ m^{-3}, what is by a factor of 3 smaller than the measured increase Although Z_{eff} was not measured directly, rough estimations have shown 2-fold increase in Z_{eff}

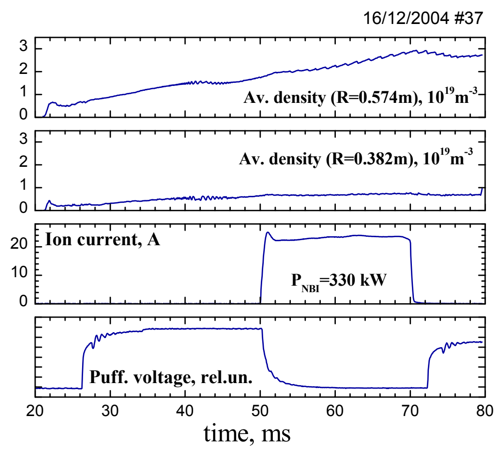

Fig. 1.Evolution of density averaged over vertical chords R=0.574m (central) and R=0.718m (outer periphery) during NBI.

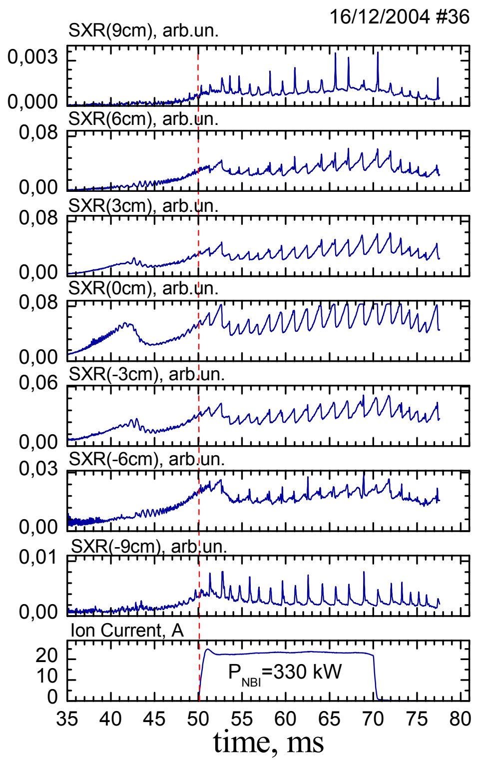

Fig. 2.Intensity of SXR radiation measured along different chords (shift from the center is indicated in brackets). Ion current in the bottom window indicates duration of NBI.

from the initial value of 1.5. Optical observations showed strong increase in the visible emission in the vicinity of NBI entrance port. All above is in line with assumption of strong effect of impurities released during NB injection. In order to reduce impurity influx the entrance port was conditioned with a several hundreds of NBI shots without/with plasma. Further improvements of the vessel and entrance port conditions have been achieved by boronization [5]. In the shots obtained after boronization the density increase during NBI was negligible and Z_{eff} increase was moderate.

Experimental results

A narrowing of the density, electron temperature and current density profiles during NBI have been observed. 10-channel microwave interferometer (λ=2.2 mm) was used to study evolution of electron density profile. Comparison of the densities averaged along central and peripheral chords showed peaking of electron density during NBI, see Fig.1. The ratio $\overline{n}(0.574m)/\overline{n}(0.382m)$ increases from 2.8 to 4.1.

Some narrowing of the electron temperature profile was derived from measurements of the intensity of SXR radiation. Temporal evolution of SXR emission measured along different chords is shown in Fig.2. Ratio $I_{SXR}(0)/I_{SXR}(0.4a)$ increases during NBI by approximately factor of 2.7. The narrowing cannot be explained by n^2 factor alone, thus $T_e(r)$ shrinkage could be concluded. Evolution of $r_s(q=1)$ during NB injection indicated narrowing

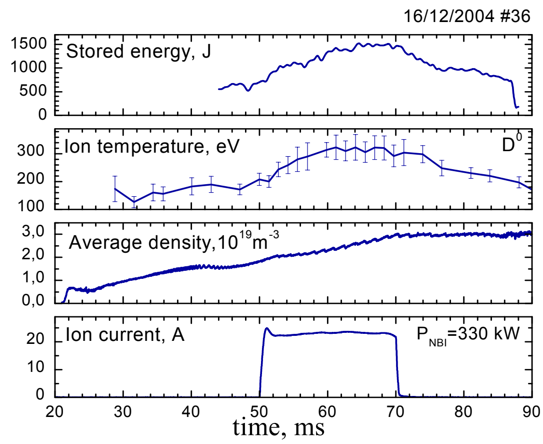

Fig. 3.Evolution of stored energy, ion temperature and averaged density during NBI heating with P_{beam}=330kW.

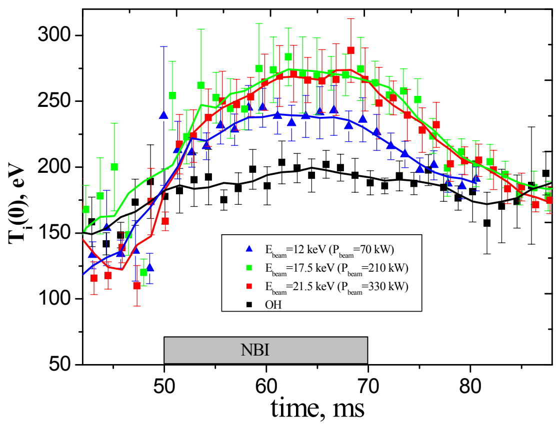

Fig. 4.Dependence of $T_i(0)$ on power of heating beam.

of the current density profile j(r). Before NBI the inversion radius is 6 cm. In the end of NBI r_s is evidently shifted outwards, see Fig.2. This means narrowing of current density profile, which might be explained by electron temperature profile $T_e(r)$ shrinkage. The observed narrowing of the profiles could be attributed to increasing Ware pinch and some current drive in the plasma core.

Moderate heating was observed in the NBI experiments. The energy content W_{dia} determined from diamagnetic measurements increased by a factor of ~ 2.5 as compared with the initial level. Measured by the Neutral Particle Analyzer the central ion temperature was increased from 190 to 330 eV, see Fig.3. Gradual saturation of ion heating with beam power was found in experiment with different P_{NBI}. Figure 4 shows the traces of $T_i(0)$ for P_{NBI} 70, 210 and 330 kW. As it is seen on the figure ΔT_i is similar for 210 and 330 kW. Effect of heating was even smaller on electron component. Although up to 70% of beam power should be absorbed by electrons, the increase in the central electron temperature was negligible.

Observed heating is smaller than predicted in assumption of validity of Merezhkin-Mukhovatov model for thermal diffusivity [3]. The contradiction with transport simulations might be understood assuming some attenuation of neutral beam in the entrance port resulting in smaller power absorption in plasma or strong effect of charge exchange and radiation losses on power balance during injection. Other possible reason of lack of heating is poor confinement of fast ions in the plasma. Preliminary data have shown fast reduction of high energy neutral flux shortly after NBI switched on. This might explain lack of heating, but reason of fast decay of high energy flux is still to be clarified.

Summary

Tests of NBI system on TUMAN-3M have been performed. Reliable operation of ion source and other components at ion current up to 30 A, beam energy 28 keV was achieved in 20 ms pulse duration. In the experiments 2.5 fold increase in the stored energy and ion heating from 190 to 330 eV have been observed with P_{NBI}=330 kW. Weak dependence of $\Delta T_i(0)$ on P_{NBI} might be explained with either losses of beam power or plasma energy losses due to charge exchange and radiation. Narrowing of density, electron temperature and current density profiles have been observed during NB injection.

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