Study of the NBCD in the spherical tokamak Globus-M

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Non-inductive current drive becomes a pressing need in application of the spherical tokamak for the reactor usage. Therefore, one of the main operational aims of the Globus-M machine is to investigate neutral beam current drive (NBCD). Noticeable NBCD in Globus-M has been observed tentatively in a number of experiments. The latest experimental results are reported in the paper together with the outcome of performed numerical simulations.

Globus-M experimental set-up and main techniques

The Globus-M spherical tokamak [1] is equipped with the mid plane neutral beam injector (NBI), which provides hydrogen or deuterium beams with the energy up to 30 keV [2]. It is capable of delivering up to 1.0 MW beam power. The impact parameter is 0.32 m (see fig. 1). Electromagnetic system of the Globus-M tokamak allows wide possibilities for plasma shaping. Typical configurations used for studying of NBCD and heating during the last experimental campaign are shown in fig. 2. The target plasmas were hydrogen and deuterium.

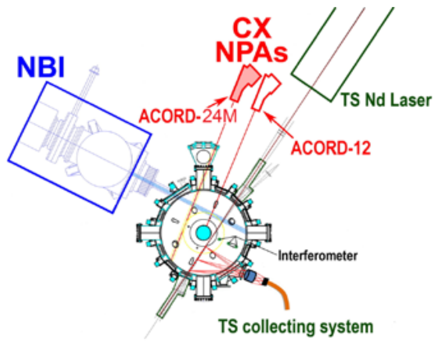

Fig. 1 Globus-M experimental set-up

The experiments were performed in the plasma current range of 0.13-0.20 MA and with the toroidal magnetic field 0.4 T. The co-injected beam was also either hydrogen or deuterium. In the experiment we used IPM-2 ion source with lower in comparison with

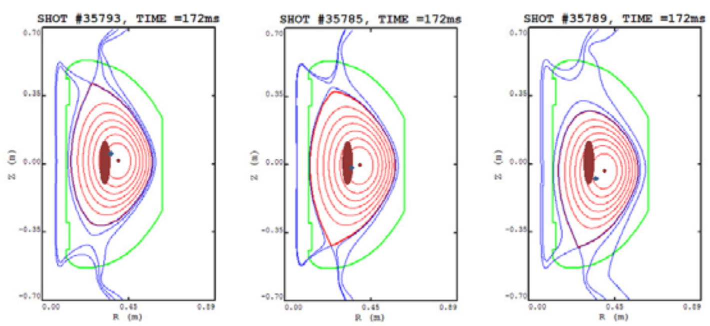

Fig. 2 Magnetic configurations with different vertical displacement (from left to right: +5cm, -2cm, -7cm correspondently). Brown ellipse – neutral beam footprint; red dot– magnetic axis; greyish-blue point – geometric center

IPM-1 output power (up to 0.5 MW), but with smaller beam cross-section of about 20×4 cm. Plasma line averaged density was monitored in vertical direction by means of the microwave interferometer. Electron temperature and density profiles were measured in mid plane with the help of Thomson scattering diagnostics. Ion component behavior was investigated with two neutral particle analyzers, which aimed in transversal and parallel to the beam line directions. Also the ion temperature was measured by means of CXRS. Magnetic configuration was reconstructed using the EFIT code [3]. The target plasma parameters were simulated with the help of ASTRA transport code [4,5]. Light impurity (carbon) spatial distribution fits to loop voltage signal. A full 3D fast ion tracking algorithm combined with the solution of the Boltzmann kinetic equation [6] was applied to calculate the beam power deposition for each beam energy fraction.

Experimental results

Plasma shot with moderate current (170 kA) was chosen as a basic target. As it is seen from fig. 3, the effect of the NBCD appeared in a short-term rise of the plasma current and prolonged drop of the loop voltage. Such behavior is defined by response of the plasma current feedback loop to additionally driven current. Initially we chose radial plasma column position, where loop voltage drop was most noticeable. A two centimeter shift of plasma column towards the tokamak axis relative to the vacuum vessel center seems to be optimal. Under these conditions we investigated a dependence of non-inductive fraction of the current on plasma density. Hydrogen beam (0.5 MW, 28 keV) was injected into deuterium plasmas during stationary phase of a discharge. The averaged density varied in the range of 1.5 -5.0 × 10^{19} m^{-3} from shot to shot (see fig.4). The values of non-inductive current calculated using ASTRA code are shown in fig.5. One can see that beam-driven current reduces with plasma density rise. Alternatively, the boot-strap current increases approximately by the same value. The total

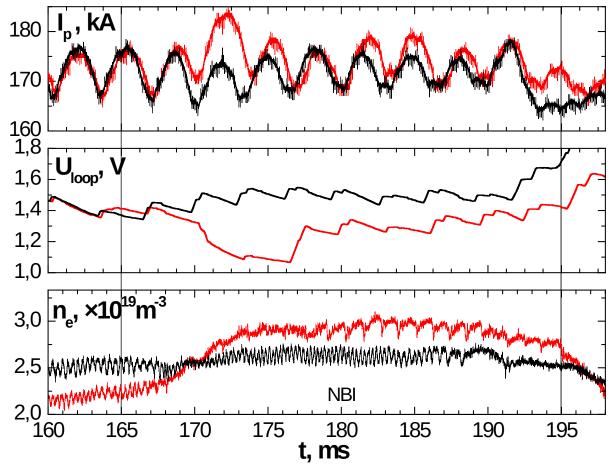

Fig. 3 Evolution of the plasma parameters during NB injection in #35783 (red) and complementary OH #35784 (black) shots. H-beam (28 keV, 0.5 MW) was injected into D-plasmas

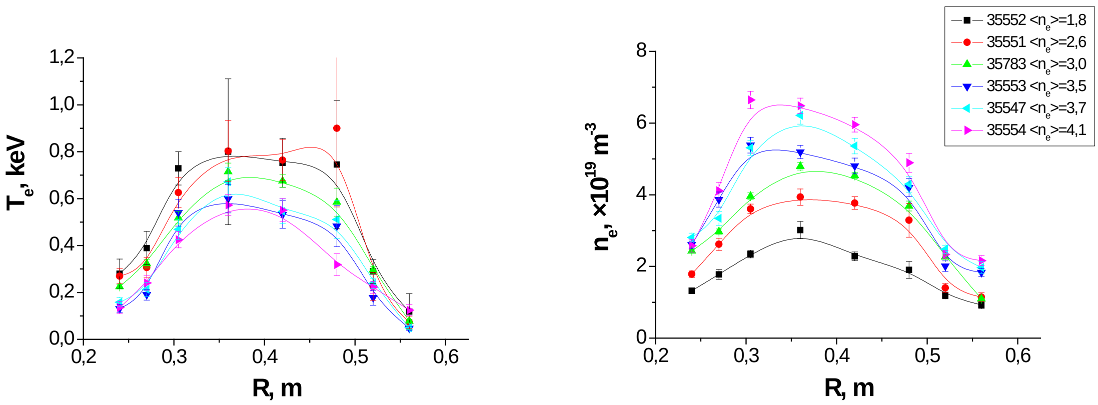

Fig. 4 Electron temperature and density spatial distribution in shots during NBI

fraction of the non-inductive current was about 17-25 % in reported experiment. The beam power, which was absorbed by plasma, did not exceed 30%.

The comparison of hydrogen and deuterium NBI into hydrogen and deuterium plasmas was performed in passed campaign. The boot-strap current is independent of isotopic combinations and increases with density definitely. Efficiency of the beam driven current is higher for hydrogen injection in comparison with deuterium one. This fact can be explained by significantly higher level of the direct (shine-through and first-orbit) losses for deuterium beam in the Globus-M tokamak because of the relatively low toroidal magnetic field. As it was reported in [6,7] direct losses can exceed 70% for low density plasmas. Experimental conditions have to change appreciably in the Globus-M2 machine [8] with significantly higher magnetic field (up to 1 T).

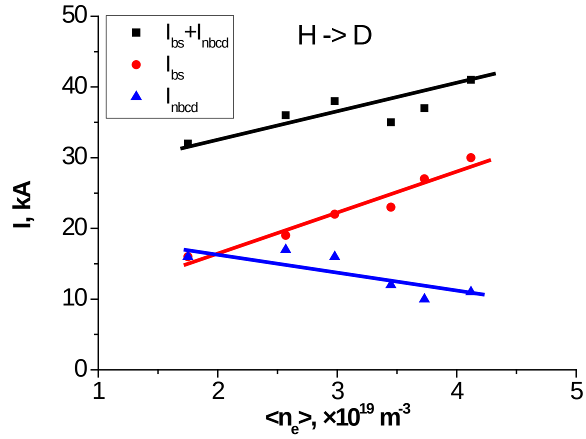

Fig. 5 Non inductive current dependence on plasma density. H-beam (28 keV, 0.5 MW) was injected into D-plasmas

The attempt of off-axis injection was made recently by displacing the Globus-M plasma by up to ±0.08 m vertically. Typical plasma column positions were shown in fig.2. We had to reduce plasma current down to 130 kA maintaining identical plasma target parameters in this experiment (see fig. 6). No significant difference in a value of NBCD was found. Simulations by means of the ASTRA code showed that beam driven current is about 13-14 kA for all shots. Nevertheless, the poloidal magnetic flux consumption Ψ_{pol} was minimal for non-shifted column position. Such behavior could be explained by some reduction of electron temperature and increase of impurity influx in the case of plasma column displacement. At the same time plasma column displacement range was at least twice smaller than the dimension of the neutral beam in vertical direction and effect was weak.

Conclusions and future plans

The performed simulations of the NBI in Globus-M indicated that around 25% of the plasma current is driven non-inductively, where the beam driven fraction is up to one half. The efficiency of NBCD reduces as the plasma density rises. Alternatively the boot-strap current increases following concentration. The off-axis NBI experiment showed negligible dependence of beam driven current on plasma column vertical displacement in Globus-M conditions.

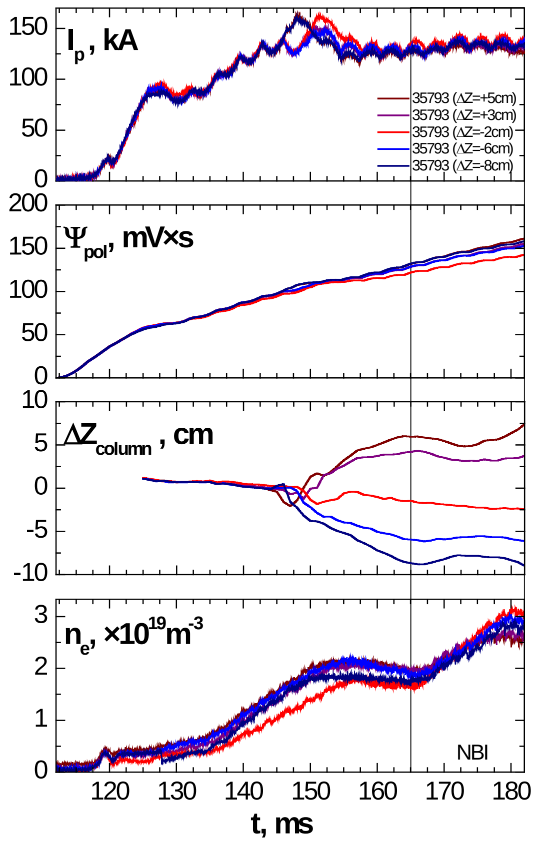

Fig. 6 Evolution of plasma parameters in shots with different plasma column vertical displacement. H-beam (28 keV, 0.5 MW) was injected into D-plasmas

Further experiments using higher NBI power are planned for the near future in order to increase non-inductive current fraction. However we expect significant progress in NB heating and current drive experiments in upgraded Globus-M2 machine, where the toroidal magnetic field attains 1 T and neutral beam direct losses fall manifold. By then a new neutral beam injector (1 MW, 50 keV, 1 s) will be installed in addition to existing one.

Acknowledgments

The work has been carried out in the Joint Research Center “Materials science and characterization in advanced technology”. V.B. Minaev, V.K. Gusev and N.V. Sakharov are grateful to the Ministry of Education and Science of the Russian Federation for the financial support (Agreement 14.621.21.0007, id RFMEFI62114X0007).

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