*31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-1.190 (2004)*

NBI Heating Experiment on the Globus-M Spherical Tokamak

V.B. Minaev[1], A.G. Barsukov[2], F.V. Chernyshev[1], I.N.Chugunov[1], L.A. Esipov[1], V.K. Gusev[1], V.G. Kapralov[3], S.V. Krikunov[1], V.V. Kuznetsov[2], V.M. Leonov[2], R.G. Levin[1], A.B. Mineev[4], M.I. Mironov[1], A.N. Novokhatskii[1], A.A. Panasenkov[2], M.I. Patrov[1], Yu.V. Petrov[1], K.A. Podushnikova[1], V.V. Rozhdestvenskii[1], N.V. Sakharov[1], A.E. Shevelev[1], G.N. Tilinin[2], S.Yu. Tolstyakov[1], V.I.Varfolomeev[1], M.I. Vildjunas[1]

[1] *A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia*
[2] *Kurchatov Institute, Moscow, Russia*
[3] *Saint-Petersburg State Politechnical University, St. Petersburg, Russia*
[4] *D.V. Efremov Institute of Electrophysical Apparatus, St. Petersburg, Russia*

Abstract. The Globus-M spherical tokamak is a low aspect ratio (R/a~1.5) device. It is equipped with the neutral beam injection system for the auxiliary plasma heating. In the 2004 campaign the investigation of the neutral beam heated plasmas in Globus-M was continued. To increase the output neutral beam power the upgrade of the injector was made. As a result the injector is able to produce 0.5-0.7 MW neutral beam (up to 30 keV, 30 ms).

The aim of the program was to optimize target plasma parameters in order to increase the absorbed beam power. The experiments were performed in the range of plasma current 0.18-0.22 MA, and the plasma density (1-4)× 10^{19} m^{-3} in a low toroidal magnetic field ~ 0.4 T near the plasma axes. The experiments were preceded by installation of additional graphite tiles in the divertor region. Vacuum vessel boronization was performed before the second series of experiment. The experimental data from routine (D-alpha, interferometer, NPA, SXR and HXR monitors, magnetic probes, EFIT) and advanced (radar-reflectometer, SXR array) diagnostics are presented in the paper as well as the results of the numerical simulation.

Introduction

Spherical tokamak Globus-M [1] was designed as a low aspect ratio device with auxiliary heating by neutral beam injection (NBI) [2] and ion cyclotron waves. The first neutral beam heating experiment was performed in 2003 [3] with moderate injection power comparable with ohmic one. It showed an increase of 40% in the electron density, 5% increase in the plasma current and nearly doubled ion temperature. The present work describes experimental results achieved with the improved neutral beam system.

Experimental arrangement

As in the previous experiment the injector was joined to a tokamak port of 40 cm in diameter and provided a neutral beam co-directional to the plasma current. The beam line was aimed tangentially to a circumference of radius R_S = 30 cm in order to reduce first-orbit losses. The length of the injection line from the ion source to the plasma outer boundary was about 2 meters. Arrangement of the experimental equipment is shown in fig. 1.

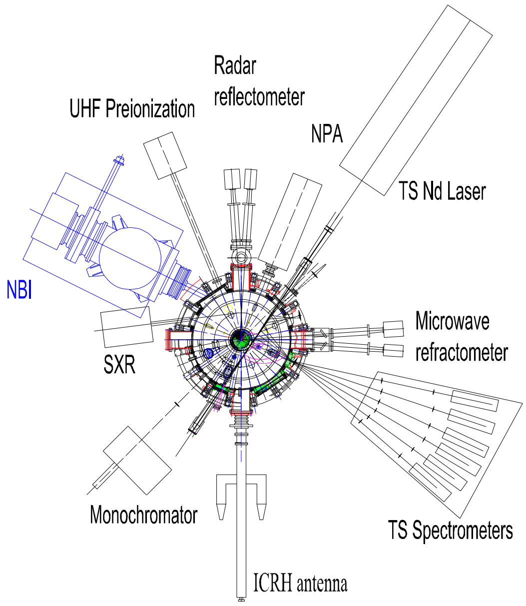

FIGURE 1. NBI layout on Globus-M.

In the experiments we used the IPM-2 ion source with multi-cusp magnetic field on the surface of the discharge chamber. A low-voltage diffuse discharge provided an ion current density up to 0.5 A/cm^2 with a non-uniformity less than 5% over 8×16 cm^2 emitter surface. The ion beam was extracted and formed by a three-electrode ion optical system. In order to increase the output beam power the improvement of the power supply system and the ion source protection system were performed. Also a high voltage conditioning of the ion source was applied. As a result the operation of injector with the acceleration voltage of 30 kV was available. The output beam power profile was measured with the help of 2D-array of secondary emission probes. Optimized profile is shown in fig. 2. The ion beam divergence did not exceed ±0.5^o in horizontal direction and ±1.5^o in vertical one. In the experiments the deuterium neutral beam of about 0.5 MW power was injected.

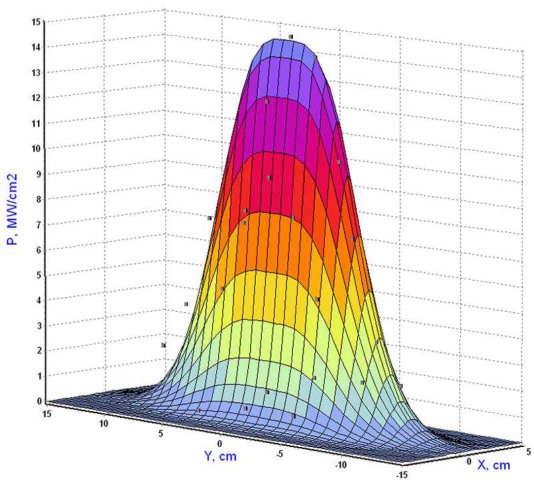

FIGURE 2. Neutral beam power profile.
P_{out} = 0.5 MW, E_D = 28 keV.

Experimental results

The experiment was performed in the following plasma parameter range: toroidal magnetic field B_0 = 0.4 T; average plasma density $<n_e>$ = (1–4)× 10^{19}m^{-3}; plasma current I_p = 0.18–0.22 MA; plasma major radius R = 0.35 m; minor radius a = 0.23 m; vertical elongation k = 1.5-2.0; triangularity δ = 0.15-0.4. The typical time evolution of plasma parameters as well as input neutral beam power waveform is sown in Fig.3. Before boronization the target plasma has central chord average electron density, $<n_e> \approx 1.4\times 10^{19}$ m^{-3}; the central electron

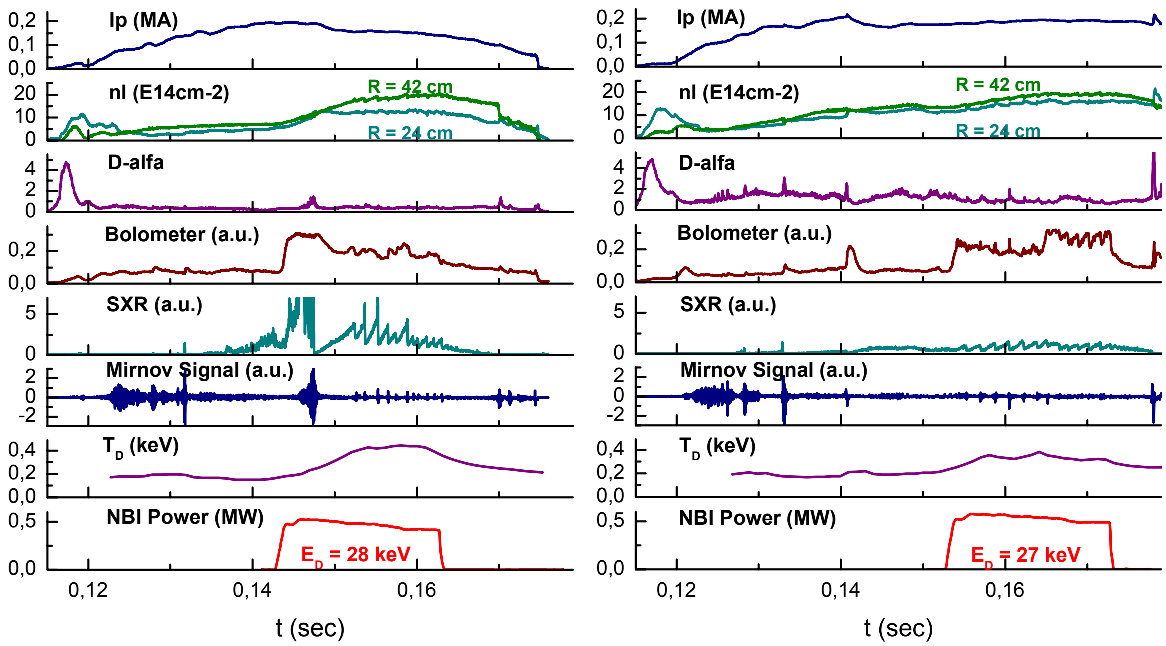

FIGURE 3. Time evolution of plasma parameters in the shots before (left, #8999) and after (right, #9099) boronization procedure.

temperature determined from the Thomson scattering, T_e = 400-500 eV; the ion temperature in the plasma bulk measured by a neutral particle analyzer, T_i = 180-200 eV. The NB pulse more than doubled the electron density along the central chord. At the same time the density rise at the periphery of the plasma column was not so significant. The ion temperature increased by 2.5 times in comparison with the ohmic stage of the discharge. Sawtooth oscillations appear after the beam pulse beginning with 1.3 ms period. The period of oscillations and its amplitude reduce after the plasma density rise stopping. After boronization we could use plasma target with higher initial density due to the moderate density rise during NB injection. The interferometer signals from central and peripheral chords showed identical density growth. The level of the SXR signal reduced. The NB injection gave 150 eV increase in the initial plasma ion temperature (~180 eV). The electron temperature in the NBI stage was found to be nearly the same as in the OH one for both experiments. The

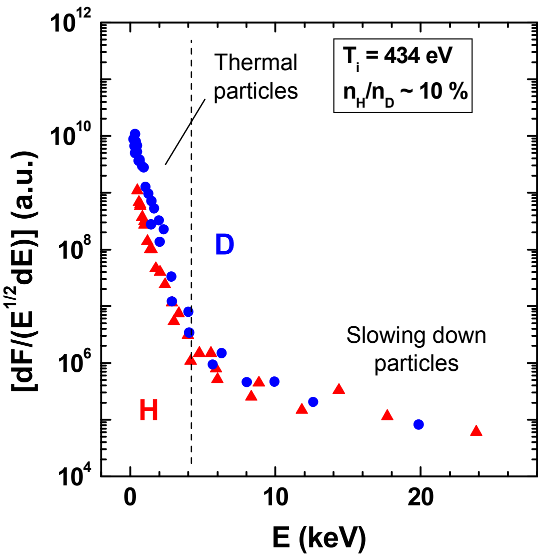

FIGURE 4. Energy spectra of charge-exchange neutrals emitted from plasma during NBI (blue circles - deuterons, red triangles - protons). Shots #8994-8999.

study of the charge-exchange neutral particle emission in the direction perpendicular to the magnetic field was performed in the energy range up to 20 keV. Figure 4 shows the energy spectra of charge-exchange neutrals measured during the injection pulse. Two spectra branches (thermal with Ti ~ 430 eV and slowing down) are clearly seen. As seen also from Fig.4, before boronization plasma contains about 10-15% protons. After boronization the proton fraction increases up to 25-30%.

Discussion and conclusions

The 0-D SCENTO code was applied for simulation of plasma behaviour in the neutral beam heating experiment in the Globus-M spherical tokamak. The EFIT equilibrium reconstruction was used as input data. Simulation shows the increase of $\langle\beta_T\rangle$ up to 5% and β_N to 2.5. The part of bootstrap current comes to 15%.

In the performed experiments the predicted by ASTRA code simulation [2] part of the NBI power absorbed by electrons is relatively low. At the level of the total injected power of 0.5 MW we cannot expect a significant increase in the electron temperature. At the same time the effective heating of ions increases the ion temperature up to the level of electron temperature and therefore reduces the electron-ion heat exchange. This can explain some saturation in the ion temperature behaviour during the NBI pulse.

In further experiments it is scheduled to extend target plasma parameters as well as to increase NB power. Also the combined ICR and NBI heating experiment is proposed.

The work is supported by Russian Ministry of Science and Education, Russian Agency of Atomic Energy as well as by RFBR grants 02-02-17693, 03-02-17659.

References:

[1] V.K. Gusev, V.E. Golant, E.Z. Gusakov, et al., "Globus-M spherical tokamak", Techn. Physics, v.44, (1999) No.9, pp. 1054-1057

[2] L.G. Askinazi, A.G. Barsukov, V.E. Golant, et al., "Preparation of Neutral Beam Injection Experiments on Globus-M and TUMAN-3M Tokamaks", Plasma Devices and Operation, v.11 (2003) No.3, pp.211-217

[3] V.B. Minaev, A.G. Barsukov, F.V.Chernyshev, et al., "First Results of the Experiment with NBI on the Globus-M Spherical Tokamak", Proc. of 30th EPS Conference on Contr. Fusion and Plasma Phys., ECA Vol.27A. (2003) P-2.174