Progress in the experiment on the neutral beam injection on the spherical tokamak Globus-M2

V.B. Minaev[1], V.K. Gusev[1], Yu.V. Petrov[1], N.V. Sakharov[1], V.I. Varfolomeev[1], P.A. Bagryansky[2], N.N. Bakharev[1], F.V. Chernyshev[1], I.N. Chugunov[1], M.V. Iliasova[1], A.A. Kavin[3], E.M. Khilkevitch[1], I.A. Khodunov[1], N.A. Khromov[1], E.O. Kiselev[1], G.S. Kurskiev[1], M.M. Larionova[1], A.D. Melnik[1], I.V. Miroshnikov[1], A.N. Novokhatskii[1], K.Yu. Oshuev[1], M.I. Patrov[1], A.E. Shevelev[1], P.B. Shchegolev[1], I.V. Shikhovtsev[2], A.L. Solomakhin[2], A.Yu. Telnova[1], V.A. Tokarev[1], S.Yu. Tolstyakov[1], E.G. Zhilin[4]

[1] *Ioffe Institute, St. Petersburg, Russia*

[2] *BINP SB RAS, Novosibirsk, Russia*

[3] *JSC «NIIEFA», St. Petersburg, Russia*

[4] *Ioffe Fusion Technology Ltd., St. Petersburg, Russia*

Introduction

The first plasma on the new spherical tokamak Globus-M2 [1] was obtained in the spring of 2018. During the test experimental campaign, the routine Globus-M shot with moderate density, plasma current of 0.2 MA and toroidal magnetic field of 0.5 T [2] was reproduced. The main discharge parameters were monitored using routine diagnostics, such as magnetic probes and loops, microwave interferometer, etc. Since the vacuum vessel in the new tokamak remained the same, the existing injector was docked simultaneously with the tokamak assembly. During testing of the injector, a beam of 26 keV 0.7 MW deuterium atoms was applied. After testing campaign, the experiment was suspended to complete work on upgrading the tokamak power supplies, setting up the diagnostics and heating and non-inductive current drive systems. At present, the tokamak operates at a toroidal magnetic field of 0.7 T and a plasma current of 0.3 MA.

Preparing for the experiment with neutral beam injection (NBI)

In the course of these works a second injector with atomic energy up to 50 keV and power up to 1 MW was docked to the tokamak (see Fig.1). Like the first one, the second beam is co-injected into the plasma tangentially in the middle plane of the torus. The impact parameter (0.3 m) was chosen in order to minimize direct losses and to provide beam transportation between turns of the toroidal magnetic field coil. The injection pulse overlaps in time the entire discharge duration, due to the injector power supply system, fed from the AC mains.

To assess the effect of a new high-energy atomic beam on plasma heating and the generation of non-inductive currents in the Globus-M2 spherical tokamak, modelling was carried out using the ASTRA code [3]. Simulations were performed for deuterium and hydrogen beams during injection into a deuterium plasma with maximum parameters I_P = 0.5 MA, B_T = 1 T. Plasma density varied in the range of $2.5 \div 15 \cdot 10^{19} m^{-3}$. Absorbed beam power was calculated by standard subroutine of the ASTRA code. Additional corrections were made for absorbed power in order to take into account first orbits losses of fast particles. These losses were determined using a three-dimensional modelling algorithm [4]. The results of these calculations are shown in Fig. 2.

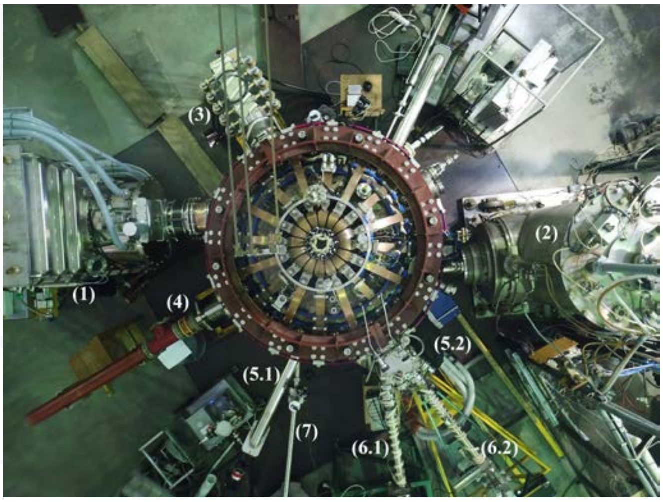

Figure 1. Layout of the auxiliary heating systems and main diagnostics on the Globus-M2 spherical tokamak (*top view*): 1 - NBI (50 keV), 2 - NBI (40 keV), 3 - ten-waveguide grill, 4 - ICRH antenna, 5 - probing beam input and collecting optics for the Tomson scattering diagnostic, 6 – neutral particle analyzers, 7 - dispersion interferometer optical input.

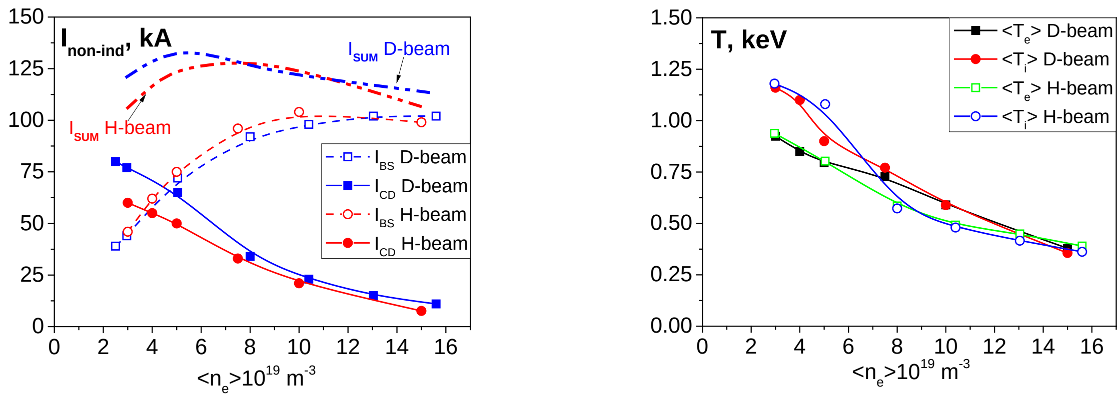

Figure 2. Dependencies of non-inductive currents (I_{BS} - bootstrap current, I_{CD} - current driven by neutral beam, I_{SUM} –total non-inductive current) – *left*, and averaged temperatures – *right* on the average plasma density for the Globus-M2 tokamak with deuterium or hydrogen NBI (1 MW, 50 keV).

The upgrade of the tokamak diagnostics

In preparation for the experiment on neutral beam injection, some new diagnostics were installed, and a number of existing diagnostics were upgraded.

Neutral particle analyzer (NPA) system was equipped with a mechanical system for the line of sight swing between tokamak shots. The scanning platform for the AKORD-12 NPA has been tested in the experiments. It allows ±10°vertical and 12° horizontal inclination from the line of sight passing through the tokamak axis in the equatorial plane. Vertical scanning system for the AKORD-24M NPA, which is mainly used to study fast ions, is under development.

Two new polychromators were added to the Thomson scattering diagnostic registration system to measure the temperature T_e and density n_e at the plasma boundary. Now the system provides measurements in 15 spatial points. The probing system includes two lasers (1055 nm, 1 J, 30 ns and 1064 nm, 2 J, 3 ns): with a tunable frequency of up to 2000 Hz and operating at a fixed frequency of 330 Hz, respectively.

To measure the linear averaged density, a single-channel dispersion interferometer was installed at the mid-plane of the tokamak. The plasma is probed along a line symmetrical the Thomson scattering diagnostics line of sight. This scheme allows direct comparison of the data of two diagnostics. The interferometer is equipped with an advanced registration system based on the FPGA matrix, which provides real-time signal phase recovery. This will allow further use of the signal from the interferometer to control the plasma density. The main advantages of the dispersion interferometer are: weak sensitivity to vibrations of the optical elements due to channel separation not in space, but in frequency; large dynamic range due to the short wavelength of 9.6 μm and a high time resolution. In the test experiment (without plasma and without a magnetic field), the following parameters were provided: the linear density resolution was 10^{16} m^{-2}; time resolution - 4 μs; spatial resolution - 2 cm.

Measurements of the neutron fluxes provide direct information on the efficiency of plasma heating. A system of neutron spectrometry diagnostics prepared for the Globus-M2 tokamak is intended for spectrometric measurements of the neutron flux. The system contains two neutron spectrometers based on the BC501A liquid scintillator (Ø2”×2”) with a decay time of 3.2 ns coupled with a PMT of Hamamatsu R329-02. The National Instruments DAQ PXIe-1082 / PXIe-5164 / PXIe-8301 with Thunderbolt 3 interface is used to record signals from spectrometers into the PC’s memory. This DAQ system provides signal acquisition with the sampling rate of 500–1000 MHz.

Neutron spectrometers BC501A were tested in measurements of the spectra of the standard sources ^{22}Na and Am-Be. The registration efficiency of the BC501A detectors for the spectrum of the Am-Be source was estimated as 0.27 for both detectors at the distance of 50 cm from the source. In addition, the BC501A detectors were tested in neutron emission measurements on a cyclotron beam. Neutron emission with the discrete energy distribution was obtained from the ^{9}Be(p,n)^{9}B and ^{9}Be(α,nγ)^{12}C reactions under a beryllium target irradiation with protons and alpha-particles accelerated in the cyclotron. As a result, the response function of the BC501A detectors to the monoenergetic emission of 3.56 MeV neutrons was measured.

Plasma experiment with an increased magnetic field

During the first experimental campaign on Globus-M2, the current through the toroidal magnetic field coil was increased up to 79 kA, which corresponds to a magnetic field of 0.72 T in the plasma geometrical center. The duration of the toroidal magnetic field flattop was artificially limited to a value of 0.1 s. The plasma current was increased up to 300 kA, and the average density was in the range of 3-6 $\cdot$ 10^{19} m^{-3}. The electron temperature in the center of plasma column has exceeded 1 keV. The plots of the main diagnostics signals are shown in Fig. 3. One can see that the typical H-mode phase switched by the NBI pulse.

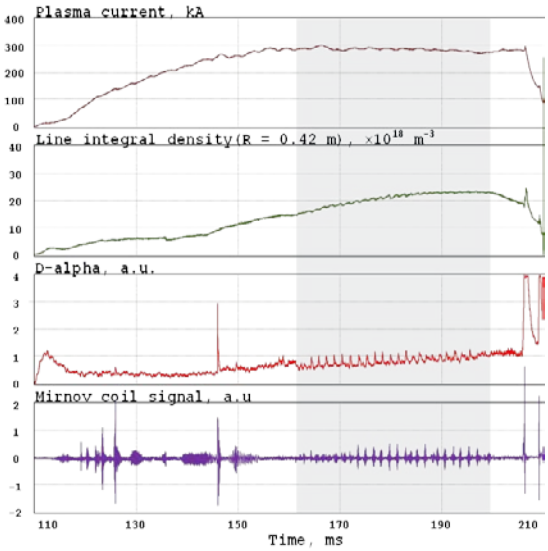

Figure 3. The evolution of the plasma current, line integral density, D-alpha and Mirnov coil signals in the shot #37827 with D-NBI (27 keV, 0.8 MW - *gray fill*).

Conclusions

During the first experimental campaign on Globus-M2 (still ongoing), D-NB was successfully injected into plasma discharges in ~~a~~ toroidal magnetic field of 0.7 T. A second NB injector with energy of 50 keV was prepared for the experiment, and it will be applied soon. After this the total output power of the NBI system will reach 2 MW. A number of diagnostic systems have been upgraded, and a new dispersion interferometer, together with spectrometric neutron diagnostics, is prepared for testing in the Globus-M2 experiment.

Acknowledgments

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