First results of plasma experiment on the spherical tokamak Globus-M2

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Introduction

Experiments carried out on the Globus-M spherical tokamak [1] have shown that the main factor hampering the improvement of the plasma parameters is a relatively low toroidal magnetic field [2-5]. An increase in the magnetic field (from 0.4 T to 1.0 T) together with an increase in the plasma current (up to 0.5 MA) in the modernized Globus-M2 tokamak [6,7] should promote plasma performance and provide improved conditions for auxiliary heating and current drive [8-12].

ICR heating in the case of an increased magnetic field and, as a result, the growth of the resonant frequency up to 15 MHz becomes more effective due to the enhancement of single-pass absorption and improvement of the antenna-plasma coupling. The use of low-hybrid waves (2.45 GHz) should ensure completely non-inductive maintenance of the current in the discharge with an input power level of 0.5 MW. An increase in the efficiency of neutral beam injection is expected due to a significant reduction in the fast particle losses in discharges with higher plasma current and magnetic field. Up to half of the plasma current can be sustained non-inductively with simultaneous input of two neutral beams of 1 MW each. In addition, during the deuterium beam injection into the deuterium plasma, the neutron flux is anticipated to be at least two orders of magnitude higher in comparison with Globus-M. As a result of joint plasma current and magnetic field rise, on the one hand, and an increase in the efficiency of the auxiliary heating methods, on the other, one could expect an improvement in the plasma parameters, including the increase in the electron temperature and the significant drop in the collision frequency. Modeling using ASTRA and NUBEAM codes predicts that the electron temperature at the core plasma should exceed 1.5-2 keV in high-density discharges ($<n_e> \geq 0.7\times10^{20}$ m^{-3}) even when a 1 MW deuterium beam is injected.

Spherical tokamak Globus-M2

Two scenarios for the plasma discharge were chosen as the basis for the operation of the upgraded Globus-M2 machine (see Table 1). The first ("B-max") assumes the work of a tokamak with a maximum toroidal magnetic field of 1 T and a plasma current of 0.5 MA, which is mainly driven by a central solenoid. The second scenario ("t-max") is intended for experiments with non-inductive current drive. In this case, the toroidal magnetic field decreases to 0.7 T, but the field plateau is prolonged as far as possible.

Table 1. Basis plasma shot scenarios for the Globus-M2 tokamak.

Engineering parameter	B-max regime B_T = 1.0 T (at R = 0.36 m)	t-max regime B_T = 0.7 T (at R = 0.36m)
Plasma current	0.5 MA	0.5 MA
Central solenoid flux consumption	0.4 Wb (+/- 0.2 Wb)	0.4 Wb (+/- 0.2 Wb)
Duration of TF flattop	≤ 0.4 s	≤ 0.7 s
Maximal number of working pulses in regime	5000	10000

A new design of the tokamak electromagnetic system was developed [8]. The internal segments of the toroidal magnetic field coils and the central solenoid were made of a durable cold-extruded copper alloy. All coils are cooled by water. The support structure of the electromagnetic system is greatly enhanced. The additional upper support ring, which is connected to the lower one by means of four load-bearing crosspieces, limits the amplitude of the displacement of the toroidal field coils at a level below 3 mm. The value of the toroidal magnetic field ripple at the outer plasma boundary was reduced to 0.4% by placing outer limbs of the coils away from the plasma boundary. In accordance with the B-max scenario, the electric current through the toroidal field coil reaches a value of 110 kA. The current swing in the central solenoid is ± 70 kA. The tokamak vacuum vessel and the in-vessel components met new conditions and remained the same that reduced project costs.

Preparation of the Globus-M2 tokamak for the plasma experiment

The Globus-M2 spherical tokamak was installed in the machine hall at the end of 2017. At that point, the power supplies feeding the facility had been upgraded. An existing injector was docked to the tokamak. The maximum energy of the atomic beam was increased up to 40 keV. Until the end of the year, in addition to it, a new injector will be applied, which provides a 50 keV atomic beam with a power of 1 MW during the entire tokamak discharge.

Both beams are co-injected tangentially to the plasma column. The work on adjusting the low-hybrid current drive system (0.5 MW, 2.45 GHz) is close to completion, including a new power supply for the klystron generator, a new antenna with a 10-waveguide grill and a waveguide splitter of RF power. An antenna for the ICR heating system has been installed into the vacuum chamber. Installation of new equipment has led to some rearrangement of the diagnostic setup. The layout of the auxiliary heating systems and the main diagnostics is shown in Figure 1. Significant changes were made to the Thomson scattering diagnostic. The optical scheme of laser probing and collection of scattered radiation was changed. Seven measuring channels were added from the low field side, which made it possible to substantially increase the spatial resolution near the last closed magnetic surface. Both NPAs have taken their places, but in the near future they will be equipped with a scanning system in the vertical and horizontal planes. To reconstruct the shape of the last closed magnetic surface, in addition to the EFIT code, an algorithm of movable current filaments has been developed and implemented.

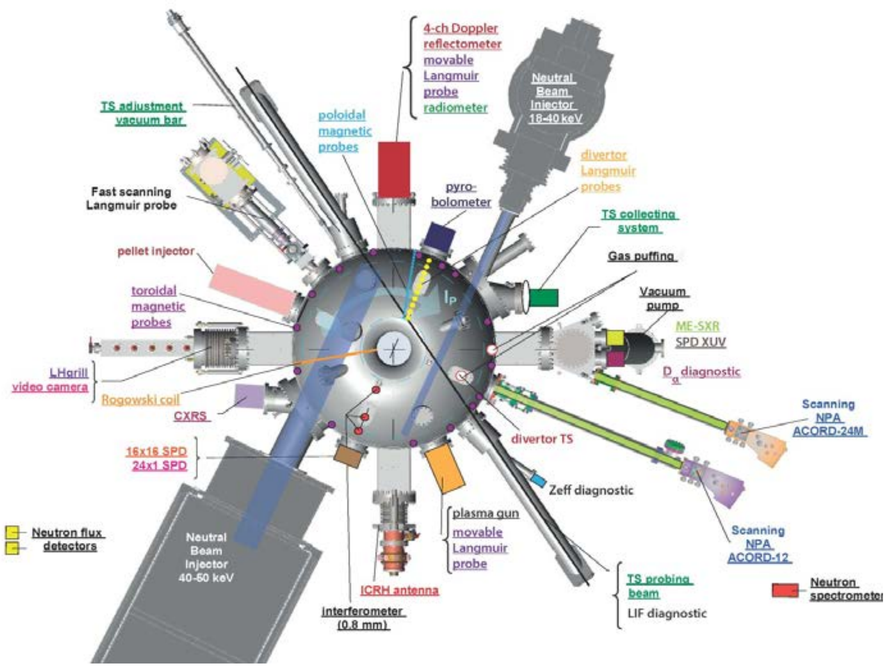

Fig. 1. The layout of the auxiliary heating systems and main diagnostics on the Globus-M2 spherical tokamak.

The electromagnetic system of the Globus-M2 tokamak was tested using standard power supplies. With the help of magnetic diagnostics consisting of a set of loops, the magnetic fluxes

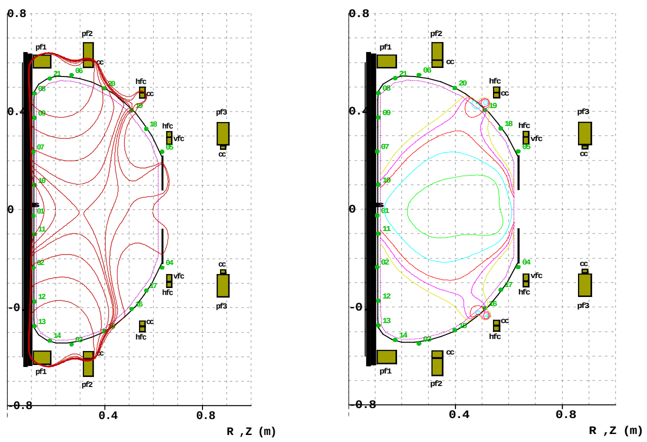

Fig. 2. The reconstruction of lines of poloidal magnetic flux (left) and equal magnetic field $|B_p|$ = 0.002, 0.005, 0.008, 0.010, 0.012 T (right) at the moment of plasma breakdown.

created by separate groups of coils were measured and the high quality of manufacturing and assembling of the tokamak electromagnetic system was confirmed. The results of the measurements were used to optimize the plasma breakdown conditions. The resulting configuration of the poloidal magnetic field is shown in Figure 2.

First results and nearest plans

The first plasma with a current of 0.2 MA was achieved in the Globus-M2 tokamak with a toroidal magnetic field of 0.5 T at the end of April 2018. Time traces of the main signals for one of the discharges are shown in Figure 3. The performed mode is analogous to the Globus-M tokamak regime. It should be noted the reduction down to 5 V of the voltage necessary for the breakdown, which indirectly confirms the higher quality of manufacturing of the electromagnetic system of the upgraded machine. A full-scale plasma experiment with an increased toroidal magnetic field is planned for the end of the year.

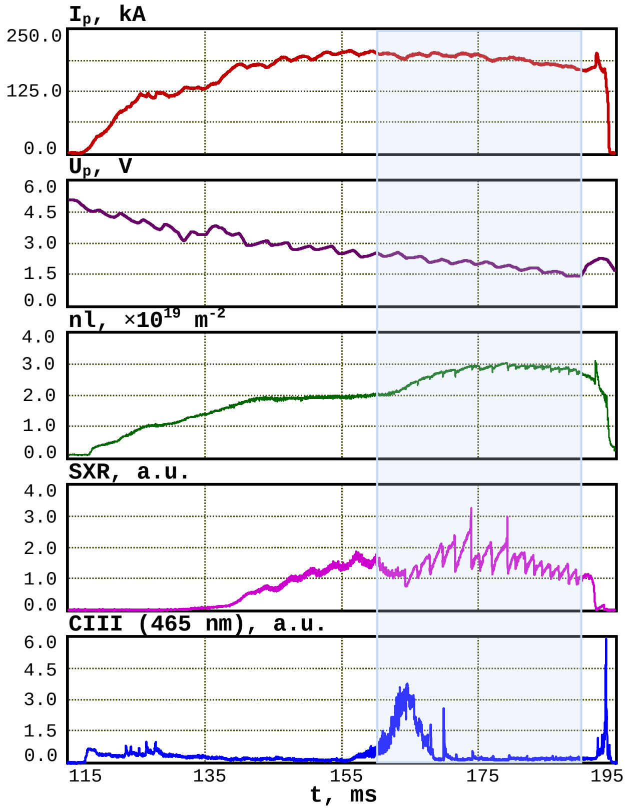

Fig. 3. The evolution of the plasma current, the loop voltage, the line averaged density, the SXR signal, the luminosity of the C III line in shot # 37269 with the D-NBI (25 keV, 0.6 MW - *light blue filling*).

Acknowledgments

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