Spherical tokamak Globus-M2 – status and scientific plans

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1. Globus-M2 integration and renovation

The main factor limiting plasma performance in spherical tokamak is a relatively low toroidal magnetic field [1]. The increase of the magnetic field up to 1.0 T together with the plasma current up to 0.5 MA will result in the significant enhancement of the operating parameters in the upgraded machine – Globus-M2 spherical tokamak [2] (Globus-M machine [3] with novel electromagnetic system and remained vacuum vessel). The manufacture of the new electromagnetic system has been going on for several years and was delivered to the Ioffe Institute at the end of 2015. Unfortunately, the power system is still being upgraded to provide the maximum current (± 70 kA amplitude in the central solenoid, 110 kA in toroidal field coils) [4]. Nevertheless, in early 2017, a trial assembly of Globus-M2 was started. One of the critical stage consisting of the assembly new electromagnetic system and remained vacuum vessel was passed. The trial assembly of Globus-M2 is presented at Fig. 1.

Renovation of auxiliary heating systems and non-inductive current drive will also planned for the Globus-M2 experiments. Taking into account growth of plasma density, maximal NB energy will be increased up to 40 keV for the existing injector. The output power of the beam stays unchanged, but the beam pulse duration will be extended. Development of a new feeding system with grid power supplies is required thereto. A new 1 MW injector [4], which provides 50 keV atomic beam, will be applied in addition to the first one. Its pulse duration fits the maximal plasma shot length in Globus-M2. Both beams will be co-injected tangentially to the plasma column. Thus, the total amount of NB heating power will be up to 2 MW. Upgrade of 2.45 GHz 0.5 MW LHCD system is on the way. The frequency range was stipulated by availability of corresponding RF system on Globus-M. A new version of the 10-

waveguide grill [2, 4] provides rotation around its longitudinal axis during the installation and, as a result, changing of wave launching direction from toroidal to poloidal one and vice-versa. The ICR heating systems will be also upgraded to fit the Globus-M2. Preliminary layout of the auxiliary heating systems and main diagnostics on the Globus M2 tokamak is presented on Fig. 2.

2. Latest Globus-M results and and Globus-M2 plasma parameter propagation.

The final Globus-M campaign in the past 2016 was carried out at 0.5 T of the toroidal magnetic field (usual Globus-M value was 0.4 T) and within these, new data on plasma confinement and auxiliary heating efficiency were obtained.

The plasma stored energy W_{tot} was estimated by volume integration of kinetic data using the approach described in [5]. The dependences of W_{tot} on density are presented in Fig. 3 on the left hand in comparison with the data obtained from the analysis of plasma diamagnetism. From Fig. 3 one can see that kinetic and magnetic data are in a good agreement. The energy stored by electrons, W_e, was derived by volume integration of electron temperature and density profiles measured by the Thomson scattering diagnostics. W_e increases with magnetic field rise as well. Contrary the central ion temperature measured by neutral particle analyzer remains unchanged or increases negligibly with magnetic field rise, therefore W_{tot} rise is caused mostly by the W_e rise. So we believe that growth in total plasma stored energy through toroidal magnetic field increase arises substantially from the electron component confinement improvement. It is remarkable fact that W_{tot} and W_e rise becomes apparent for plasma shots with density higher than $2\text{-}3{\cdot}10^{19}$ m^{-3}. That may be due to difference in turbulence for linear and saturated ohmic confinement regimes, which influences the electron thermal insulation. Also we made estimations of the energy confinement time using kinetic W_{tot}. Fig. 4 shows its dependence on the averaged plasma density for two different values of magnetic field. One can see, that the confinement time increases approximately from 4.5 ms up to 5.5 ms for the averaged density of about $5{\cdot}10^{19}$ m^{-3}. That is approximately proportional to the toroidal magnetic field. Though the estimations are rough, the performed experiment has demonstrated improvement in thermal insulation of electrons as well as plasmas in whole due to toroidal magnetic field rise. That looks very promising for future experiments on Globus-M2.

Also ~ 30% D-D neutron rate growth was observed after the plasma current and magnetic field increase in the set of the testing experiments (Fig. 5) demonstrate the increase of neutron yield in the discharges with the 26 keV D-beam injection into deuterium plasma. The main reasons for this in order of importance are the central electron temperature rise (from ~ 600 eV to ~ 900 eV) and the fast ion losses decrease [1, 2]. Improvement in fast ion confinement is demonstrated in the experimentally measured CX spectra presented in Fig. 6. The value of plasma current is more important in this case. Reduction of the first orbit and slowing down losses of the injected particles together with decrease of the saw-tooth oscillations impact on the energetic ion confinement resulted in the change of the CX spectra shape.

The influence of toroidal magnetic field on non-inductive current drive efficiency was investigated in an experiment. The hydrogen beam (1 MW, 28 keV) was injected into deuterium plasmas (Ip = 170 kA, <ne> = $2.5\cdot10^{19}$ m^{-3}) during current flat top. The increase of the magnetic field from 0.4 T to 0.5 T was accompanied by a more significant drop in the loop voltage during the NB injection. The poloidal magnetic flux consumption for the NB and ohmically heated shots is shown in Fig. 7. It demonstrates about 10% reduction in the volt-second consumption for the compared shots due to toroidal magnetic field rise and accompanying improvement in the fast ion confinement.

3. Conclusions and acknowledgements.

The Globus-M2 project is aimed at research of non-inductive current drive and plasma heating methods in a low aspect ratio magnetic configurations and development of a compact fusion neutron source based on the spherical tokamak. The construction of the new device is at the final stage. Simultaneously, the last experimental results obtained at the 25% higher magnetic field showed applicability of numerical techniques developed earlier. All this makes it possible to count on obtaining new interesting results on Globus-M2 in 2018.

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Fig. 1. The trial assembly of Globus-M2.

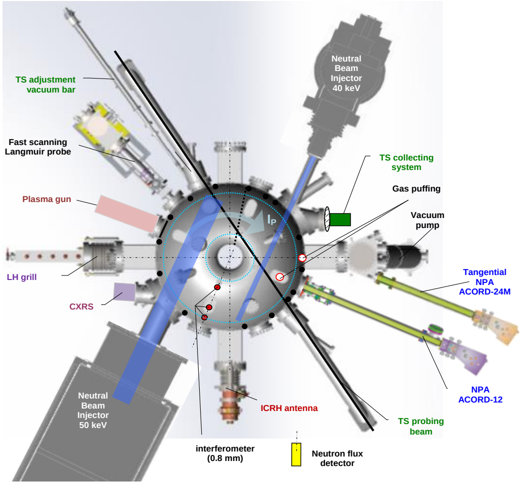

Fig. 2. Preliminary layout of the auxiliary heating systems and main diagnostics on the Globus-M2 tokamak

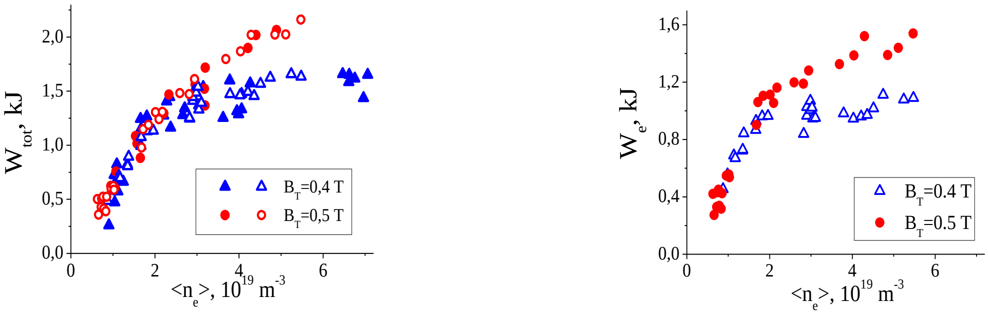

Fig. 3. Left: Total plasma stored energy as a function of density in the ohmic shots with 200 kA current and toroidal magnetic field of 0.4 T and 0.5 T. Solid symbols correspond to diamagnetic measurements, open symbols correspond to kinetic data. Right: Energy stored by electrons as a function of density in the ohmic shots with 200 kA current and toroidal magnetic field of 0.4 T and 0.5 T.

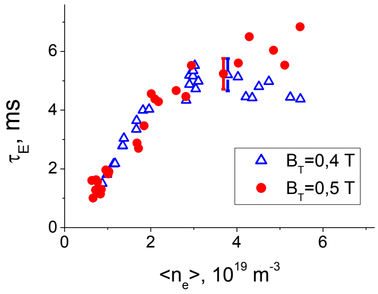

Fig 4. Energy confinement time as a function of density in the ohmic shots with 200 kA current and toroidal magnetic field of 0.4 T and 0.5 T.

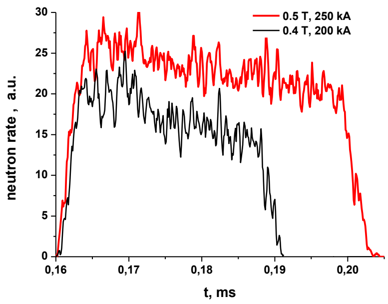

Fig. 5. Time traces of neutron rate in 0.4 T 200 kA (#36639) and 0.5 T 250 kA (#36618) discharges.

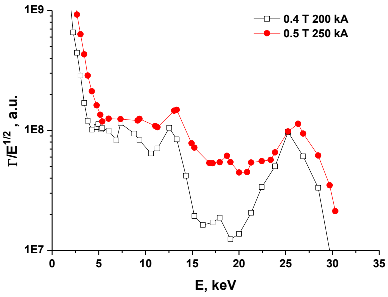

Fig. 6. The CX spectra measured by NPA in 0.4 T, 200 kA (#36618-36620) and 0.5 T, 250 kA (#36639, 36641, 36642) discharges.

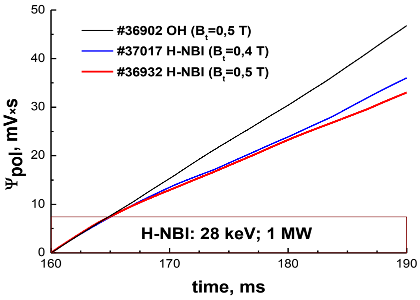

Fig. 7. The poloidal magnetic flux consumption for NB heated (#37017, #36932) and ohmic (#36902) discharges.