GLOBUS-M EXPERIMENT AT THE FINAL STAGE OF PREPARATION

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Abstract

Globus-M spherical tokamak was designed and constructed in the framework of International Science and Technology Center. The work was performed as a joint effort of institutions listed in the title. Final technical characteristic of the machine are better than the design parameters. The nominal plasma current is increased up to 0.5 MA, the toroidal magnetic field is increased up to 0.65 T. Major radius is 0.36 m, minor radius is 0.24 m, aspect ratio is 1.5, vertical elongation is 2.2, pulse duration is 0.2 s (at 6 pulses/hour rate operation). Device performance is discussed with focus on details which could improve experimental program and make the machine operation more reliable. Experimental program steps, starting from ohmic heating regime optimization and completing RF auxiliary heating and CD methods are described. Some results of RF simulation performed in the range of frequencies 10 MHz÷2.45 GHz are presented. Application of such methods for local plasma parameters profiles modification is discussed. Brief description of first stage diagnostics and of the advanced diagnostics equipment for the second stage is made. Current project status is discussed.

1. DEVICE PERFORMANCE

Globus-M tokamak was recently delivered and installed in the new experimental machine hall, specially built at A.F.Ioffe institute for the project needs. Total area of double stage machine hall is 600 m^2 which is enough for disposition around tokamak all necessary technological, diagnostic and auxiliary heating/current drive equipment.

The device vacuum vessel has big number of ports (38) of total area about 0.8 m^2 which ensure convenient access to plasma for column diagnostics, auxiliary heating and CD. Close vessel fitting design and small ballast volume together with large area equatorial plane ports provide adequate conditions for effective launch of high RF auxiliary heating power. Possible to use also NBI line. Ports allows to launch up to 8 MW of total power.

The tokamak is fed via 110 kV National Grid through phase controlled thyristor rectifiers. Power supplies together with fast (3 kHz) current inverters used for plasma column position and shape control are looped through feedback circuit to ensure operation at constant current and shape of the plasma column, even when auxiliary heating power is applied [1]. Together with water cooled coils of electromagnetic system power supplies create big credit for increase of pulse duration, which at present design and materials used is limited to one second. This is more than enough for complete relaxation of current density profile.

Important characteristics of spherical tokamak are ultimate values of toroidal magnetic field and plasma current. The design modification allowed to increase central rod current in Globus-M up to 1.2 MA which led to higher value of axial toroidal magnetic field ~ 0.65 T. This fully ensures the routine machine operation at plasma current of 0.5 MA. The ultimate value of plasma current still satisfying kink modes stability criteria is very high for such small machine as Globus-M and could be fairly close to the central rod current. START experiment had demonstrated the possibility of low q_{edge} operation in the set of experiments [2]. With $q_{edge} \cong 3.6$, $B_T \cong 0.62$ T Globus-M could in principal achieve ≈ 1 MA of plasma current. This value could be, of course, regarded as an ultimate one for the limited number of shots in the regimes with non-inductive CD and requires further development of discharge control methods and technology of power and particle handling. To provide routine operation with the design values of plasma current the volt-second capability of poloidal field coils system (0.33 V·s) with the main contribution of central solenoid (0.3 V·s) is enough. Central solenoid is described in [3].

Current density in Globus-M tokamak achieving in average 1.4 MA/m^2 even at routine regime operation is very high comparatively most other spherical tokamaks under construction. This makes ohmic heating regime more effective as high specific power deposition, proportional to j^2, could benefit for higher edge temperatures and decrease the influence of resistive MHD instabilities. High current density, as well as high B/R = 1.8 T/m permit the operation at high absolute density limit of about 2×10^{20} m^{-3} even for gas puff scenario of plasma fueling. Operation at low q_{edge} with high current density is an attractive domain for beta limits investigation in ohmically heated plasmas, as it allows to reach high values of normalized current $I_N = I_P/aB_T$. Stability simulations of plasma column for double null configuration with I_N = 4.4, q_{edge} =3.3 shows that it's stable for high-n ballooning modes at $\beta_T \approx 18\%$ in the first stability zone [4]. The outlook of the spherical tokamak Globus-M installed in the new experimental machine hall at Ioffe institute is shown in Fig.1.

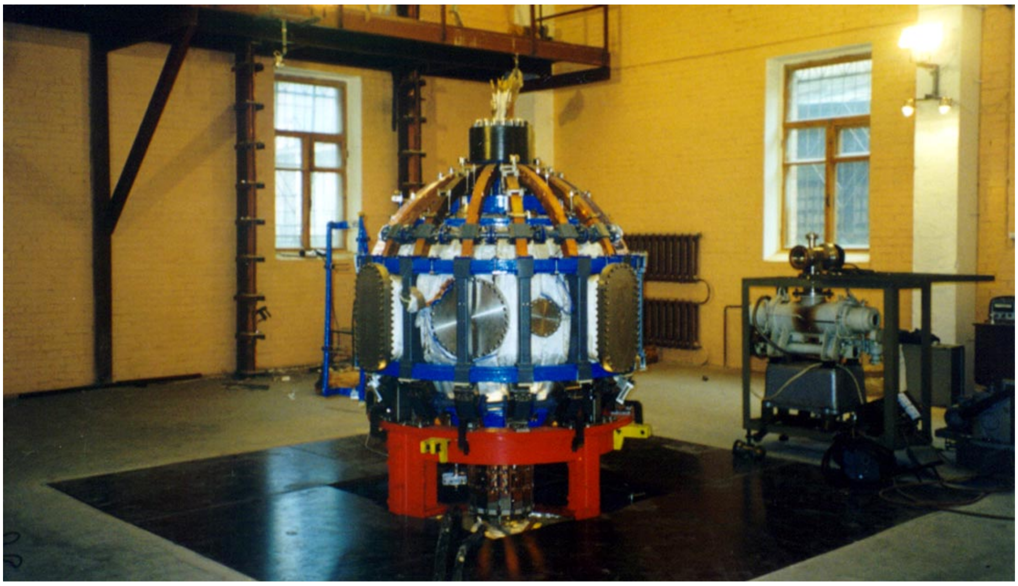

FIG. 1. Globus-M tokamak in the experimental machine hall

2. EXPERIMENTAL TOOLS AND METHODS

Ohmic heating regime optimization is the first experimental program step which will be performed using conventional methods of plasma initialization, maintenance and control. The set of compensation coils is responsible for suppression of central solenoid stray magnetic field in major part inside of the vessel. The plot of poloidal B contours in the Globus-M vacuum vessel for the case of central solenoid flux compensation is shown in Fig.2. The coils are feedback controlled. To minimize requirements for the breakdown fields the plasma preionization with the help of 15 GHz magnetron will be performed. Plasma current ramp-up method is fully inductive for the first experimental program step. According to predictive simulations it requires ~0.18 V·s to achieve 0.3 MA of plasma current. Current ramp-up speed is about 5MA/s which is an order of magnitude less than used in START experiment. Plasma column stability is provided by close fitting vessel properties (image currents) from one hand and automatic feedback control from another. First one is responsible for suppression of fast vertical plasma column movements, as well as for stabilization low-n kink modes by the conducting wall. Another possibility to reduce MHD activity of plasma column is to drive current in SOL through segmented divertor plates [5]. Segmented divertor plates of Globus-M tokamak which are insulated from each other and from vacuum vessel provide such opportunity with minimum rearrangement. The picture of Globus-M divertor plates and ribs (in-vessel components) before installation them inside the vessel is shown in Fig.3.

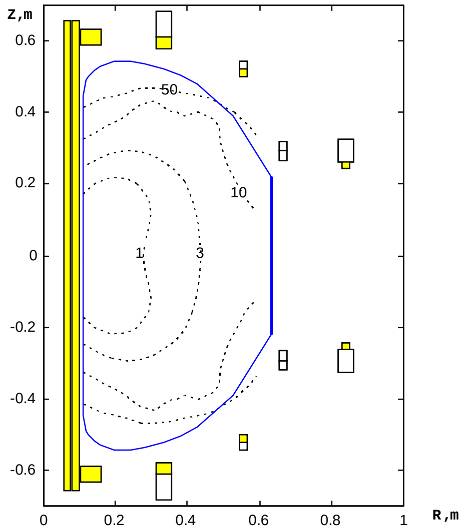

FIG. 2. Breakdown phase poloidal field structure at central solenoid current of 70kA

FIG.3. In-vessel components

Powerful ohmic heating and auxiliary heating of plasma in conditions of close fitting vessel wall require the development of power and particle fluxes handling technology. Along with conventional methods of wall conditioning special attention was paid for the choice of plasma facing materials and the design of in-vessel components. The divertor and central cylinder protection plates are stainless steel sheets and can be coated with different plasma facing materials. B, Be and C layer covering technology is available. An easy access for removing and exchanging of those plates is provided through two special manholes of big diameter (400 mm) in short time interval.

The further development of RF auxiliary heating and CD methods proposed in [1] were made. For the frequency range of 6÷50 MHz, covering ion cyclotron resonance harmonic numbers from first to eight's the modeling of fast magnetosonic wave propagation and absorption has been carried out in quasi-toroidal geometry, taking into account the poloidal and paramagnetic field component [6]. The code solved 1-D wave equation with hot dielectric tensor and finite Larmour radius corrections up to the 2nd order. Landau, TTMP and cross term damping were also taken into account. A sufficiently strong single pass absorption (up to 80%) is predicted for fast magnetosonic waves in Globus-M. Local power deposition profiles integrated for whole spectra are shown in Fig.4. The fundamental harmonic ion cyclotron heating power deposition profile is fairly narrow (Fig.4a), whereas HHFW power deposition at 30 MHz provides electron heating in rather broad region of plasma of about half of minor radius (Fig.4b). Sharp spike corresponds to the power absorption by the small fraction of protons at the second harmonics of ion cyclotron frequency. This effect could be used for local modification of plasma pressure profile by the transmitter frequency tuning, which does not influence significantly on the global power absorption and plasma heating.

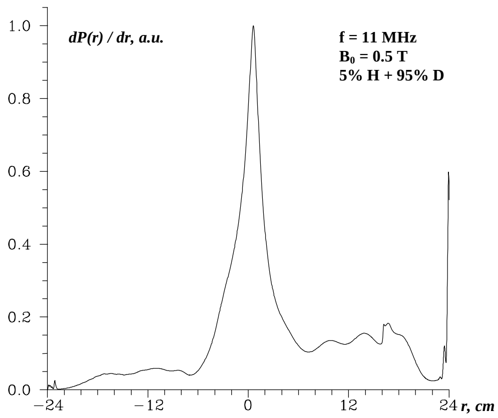

FIG. 4a. Power deposition at fundamental harmonic ICR

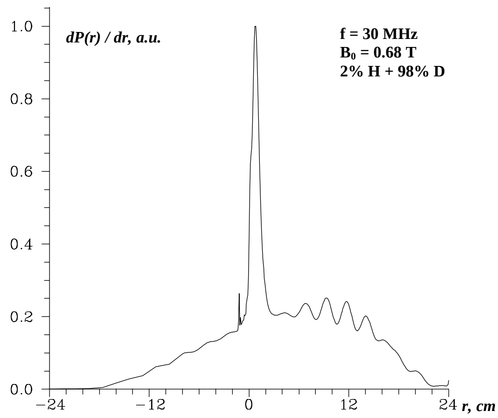

FIG. 4b. Power deposition at HHFW heating scenario

Conventional schemes of lower hybrid waves excitation is not effective in spherical tokamaks because of large $N_{\|} = 7\div10$. However strong poloidal inhomogeneity of the magnetic field provides the possibility of using new heating scenario: the waves with frequencies $\omega \leq eB_{pol}/m_e c$ and with low initial $N_{\|} = 2\div4$ launched from the equatorial plane in the poloidal direction can go inside and be effectively damped as their $N_{\|}$ increases along the trajectory due to poloidal magnetic field inhomogeniety. The efficiency of grill antenna rotated by 90^o positioned in the equatorial plane is rather high and the reflection coefficient is reduced to 10÷15%, if the plasma density profile is not very steep. Ray-tracing simulations showed that the power is absorbed at $r \approx (0.3\div0.7)\cdot a$ depending on the plasma parameters: lower n_e and T_e at the periphery result in more central power deposition. The higher values of the total plasma current provides better matching conditions at the plasma boundary with the increase of current drive efficiency , which could be as high as 0.04×10^{20} $A/m^2\cdot W$ [7].

The adequate to investigation tasks set of diagnostics equipment is constructed or under development now for Globus-M tokamak. Detailed electromagnet measurements (2×36 magnetic probes array, magnetic loops and coils), plasma imaging at the reduced rate and line integrated parameters measurements will be performed at the first stage of the experiments. Corresponding equipment is under preparation. The set of diagnostic equipment for detailed measurements of plasma parameter profiles includes, in particular, four advanced diagnostics. They are Pulse Radar Reflectometer, Thomson scattering system, SXR diagnostics and plasma imaging camera. Pulse Radar Reflectometer is the combination of commonly used frequency swept phase reflectometer and pulse RADAR instrument. Thomson scattering system with Nd glass laser generating a pulse train of 20 pulses/shot with 20 J/pulse output energy and avalanche silicon detectors providing excellent sensitivity limit - 1×10^{17} m^{-3} is under design together with two SXR pinhole cameras for plasma tomography with capability to measure electron temperature and high speed video camera with instantaneous exposure control for plasma imaging at very high dynamic range.

3. STATUS

The tokamak is vacuum and electrically tested and installed on the vibrodamping basement. Current feeders for the electromagnet system are connected. The connections to vacuum pumps, cooling and baking systems are under way. Control systems for plasma column control and power supplies are under final stage of preparation. Cable lines for control are under construction. Tokamak systems complex tests are planned for November, 1998. Total power supply system energizing is scheduled for December 1998 as well as tokamak shake down and first plasma.

[1] GOLANT, V.E., et al., “Basic peculiarities of Globus-M spherical tokamak project”, Fusion Energy Conference, (Proc. 16 IAEA Conf. Montreal, Canada, 1996), IAEA-CN-64/GP-15.

[2] GRYAZNEVICH, M.P., et al., “Achievement of record beta in the START spherical tokamak”, Phys. Rev. Lett **80** (1998) 3972.

[3] GUSEV, V.K., et al., “Central solenoid for spherical tokamak Globus-M”, Fusion Technology **34** (1998) 137-146.

[4] MEDVEDEV, S. Yu. “On limiting plasma pressure in low aspect ratio tokamak”, Spherical Torus’97 (Proc. Int. Workshop St. Petersburg, Russia, 1997) **1** (1997) 403.

[5] GOLDSTON, R.J. “SOL currents for feedback stabilization of MHD modes”, Controlled Fusion and Plasma Phys. (Proc. 24 EPS Conf. Berchesgaden, Germany, 1997) **21A**, III (1997) 1061.

[6] IRZAK, M.A., et al., “Modeling of RF heating experiments in the spherical tokamak Globus-M”, to be published in Fisika Plasmy.

[7] ESTERKIN, A.R., et al., “RF heating in Globus-M tokamak at lower hybrid frequencies”, Spherical Torus’97 (Proc. Int. Workshop St. Petersburg, Russia, 1997) **1** (1997) 265.