

First Plasma Experiments on Spherical Tokamak Globus-M

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Abstract

The first plasma experiments on spherical tokamak Globus-M are described. Globus-M is a low aspect ratio tokamak (plasma major radius $R = 0.36$ m, minor radius $a = 0.24$ m, $R/a = 1.5$). The first plasma in Globus-M was achieved in ultra low toroidal magnetic field $B_T \sim 0.1$ T. The inductive plasma breakdown near the vessel centre stack is assisted by RF preionization in the vicinity of electron cyclotron resonance. Two resonance frequencies are used in the experiments: $f = 2.4$ GHz ($B_{res} = 0.086$ T) and $f = 9.4$ GHz ($B_{res} = 0.34$ T). The vacuum vessel conditioning includes bakeout at the temperature of 200^0 C and glow discharge cleaning in He. Four pairs of poloidal field coils are used for the compensation of central solenoid and vacuum vessel stray magnetic fields and for the monitoring of naturally elongated plasma major radius position. The initial plasma current start-up at a rate up to 10 MA/s is described. The current status of the full-scale plasma experiments is outlined.

1.Introduction

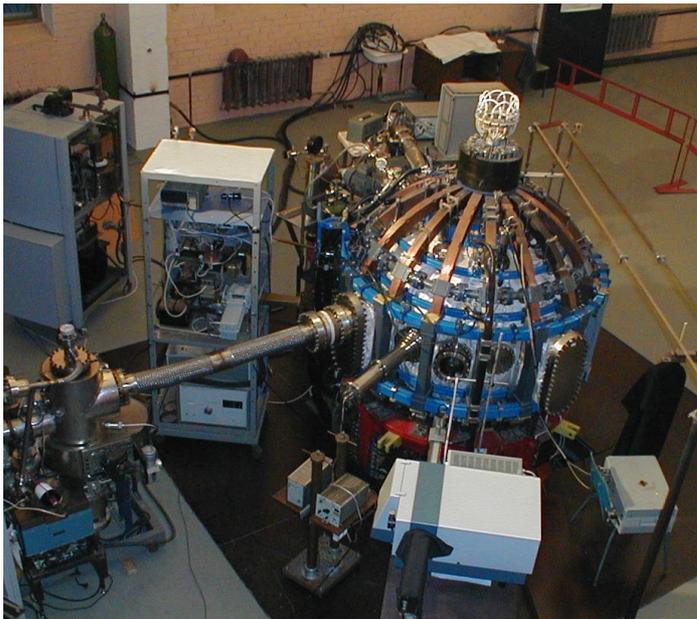


Fig.1. View of Spherical Tokamak Globus-M.

Spherical tokamak Globus-M is constructed for plasma experiments at the Ioffe Institute, St.Petersburg [1]. The machine view is shown in Fig.1. One of the basic requirements determining the device performance is a compatibility of currents in magnets with existing power supplies. There are four thyristor rectifiers capable of 70 kA current each at the voltage of 450 V and four thyristor rectifiers of 4 kA each at the voltage of 850 V. The total power of 125 MVA is provided by the national electric network. The toroidal field (TF) can reach the value of 0.62 T at the radius $R = 0.36$ m.

The magnetic flux swing in the central solenoid of ± 0.15 Wb is sufficient for generation and maintenance of plasma current up to 0.5 MA. A few “fast” thyristor choppers with a frequency up to 3.5 kHz are used for monitoring of vertical and horizontal position of vertically elongated plasmas through the circuits of feedback control. It is expected to complete the power supply commissioning during the summer of this year and then to start full-scale plasma experiments.

In general Globus-M is constructed like a conventional tokamak. All the poloidal field (PF) coils are positioned outside the thin-wall stainless steel vacuum vessel. The sixteen single-turn TF coils are connected in series. The TF coils are self-supported. Also they are used as the supports for nine pairs of PF coils.

The first plasma in Globus-M was achieved by using temporary power supplies. The TF coils and the central solenoid were fired by 5 kV banks. The PF coils were energized by the thyristor choppers, which were fed with 300 V electrolytes. The plasma current of 30 kA was achieved in a very low toroidal magnetic field $B_T \sim 0.1$ T at $R = 0.36$ m. The plasma breakdown by the central solenoid inductive voltage was assisted by a radio frequency (RF) preionization in the vicinity of electron cyclotron resonance. The details of first plasma experiments are described in the paper.

2. Vacuum Vessel Conditioning.

The vacuum vessel bake-out temperature is 200⁰C. The inner cylinder of the vessel of 0.22 m diameter is heated inductively by the 400 Hz current in the central solenoid. The other parts of the vessel wall and the basic ports are heated by a high resistance cable. The temperature is automatically controlled by thermocouples positioned in 41 points. The residual gas spectrum is monitored by the mass-spectrometer. The steady-state temperature of 200⁰C is reached during 3 hours at a heating power less than 10 kW.

Glow discharge cleaning in He and H₂ during 2-3 hours is used every day before the plasma experiment. The water cooled electrode (anode) is positioned in a shadow of 380 mm diameter port. The glow discharge breakdown pressure is 10⁻² torr at the voltage of 1 kV. The discharge current is 0.8 A at a pressure $\leq 10^{-3}$ torr, current density on the vessel wall is about 160 mA/m². The boronization technique [2] which is under preparation for the full-scale plasma experiments is based on the usage of carboran C₁₂B₁₀H₁₂. The carboran powder is evaporated at a temperature 100⁰C. An amorphous film with B/C ratio about 2-3 is deposited on the vessel wall by means of glow discharge in a 50% mixture of He and carboran. The graphite tiles have been manufactured for a protection of the vessel inner cylinder. The material is a recrystallized graphite RG-Ti91. It has a low ion spattering coefficient, a high thermoconductivity and a small porosity, that means a low volume trapping of hydrogen.

3. RF Preionization.

The comparative study of RF preionization at two frequencies of electron cyclotron resonance (ECR) and different levels of power was carried out. In the first case the magnetron of continuous operation generated a low power ≤ 600 W at the frequency of 2.42 GHz, that corresponds to the wavelength $\lambda = 12.4$ cm and the resonance magnetic field $B_{res} = 0.0864$ T. The output power of the second magnetron generator is up to 40 kW in a short pulse of 0.6 ms length, the frequency is 9.4 GHz ($\lambda = 3.2$ cm), $B_{res} = 0.34$ T. In the both cases the RF power was delivered to the vessel from the low TF side. In the first experiments the total current in TF coils, i.e. the current in TF central rod I_{rod} could not exceed the value of 224 kA. Under these conditions the ECR layer for the 9.4 GHz frequency was located near the vessel inner cylinder at the radius $R=0.13$ m.

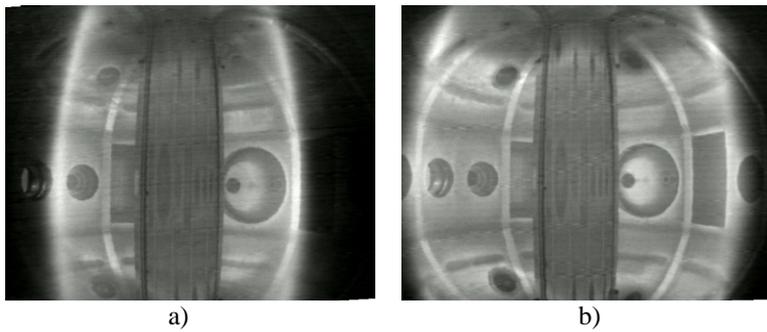


Fig.2. Plasma ECR Breakdown

RF power $P_{RF} = 300$ W, $\lambda = 12.4$ cm

a) $I_{rod} = 120$ kA, $R_{res} = 0.28$ m; b) $I_{rod} = 164$ kA, $R_{res} = 0.38$ m

The 2.42 GHz resonance layer was moved in the experiment within $R=0.37-0.52$ m depending on $160 \leq I_{rod} \leq 224$ kA. The hydrogen pressure at the breakdown phase was changed in the range $2 \times 10^{-5} - 1 \times 10^{-4}$ Torr. Plasma emission from the resonance layer is shown in Fig.2 for two TF values. The picture is made by a wide-angle videocamera, positioned in the tokamak midplane.

The both methods of RF preionization reduced significantly the electric breakdown voltage from 8 V to 1 – 2 V.

The inductive plasma breakdown occurred near the vessel inner wall. In the



Fig.3. Plasma inductive breakdown near the vessel inner cylinder.

Electric field $E \sim 2$ V/m, $I_{rod} = 160$ kA,

$\lambda = 12.4$ cm, $R_{res} = 0.37$ m

experiments the position of plasma inductive breakdown did not depend on the position of PF null in the breakdown phase, the RF power and the wavelength of generator. Plasma emission at the moment of inductive breakdown assisted by RF preionization is shown in Fig.3. The toroidal plasma current occurs in the region of $R \sim 0.12 - 0.2$ m, where the poloidal stray field, calculated on the base of experimental measurements in the absence of plasma, was in the range of 20 Gs.

4. Plasma Current Start-up.

The time evolution of plasma parameters during inductive current start-up is shown in Fig.4. Plasma current I_p is measured by the Rogowsky coil placed inside the vessel. Plasma voltage U_p is measured at the radius $R = 0.11$ m. The vessel toroidal resistance is about 0.1 m Ω . For this reason the toroidal current in the vessel reaches 40 kA in the initial phase of the discharge. In the described experiments the plasma radial position was sustained by the preprogrammed currents in PF coils. Plasma dimensions can be roughly estimated by means of 2 mm interferometer, which measures the plasma line integrated density $\langle n_l \rangle$ along two vertical chords positioned at the radii $R = 0.24$ m and $R = 0.42$ m. The comparison of two $\langle n_l \rangle$ signals in Fig.4 indicates, that centre of the plasma column is positioned near the radius $R \sim 0.36$ m, when the plasma current reaches the maximum value of 30 kA. It means, that the plasma volume is sufficiently large despite the low toroidal magnetic field and low current density. The central solenoid magnetic flux necessary for generation of 30 kA plasma current at the rate of ~ 10 MA/s is $\psi \sim 17$ mWb. This value comprises ~ 4 mWb required for the plasma breakdown and 3 kA plasma current start-up.

The preliminary modelling was performed by means of a simple 0-D model for a

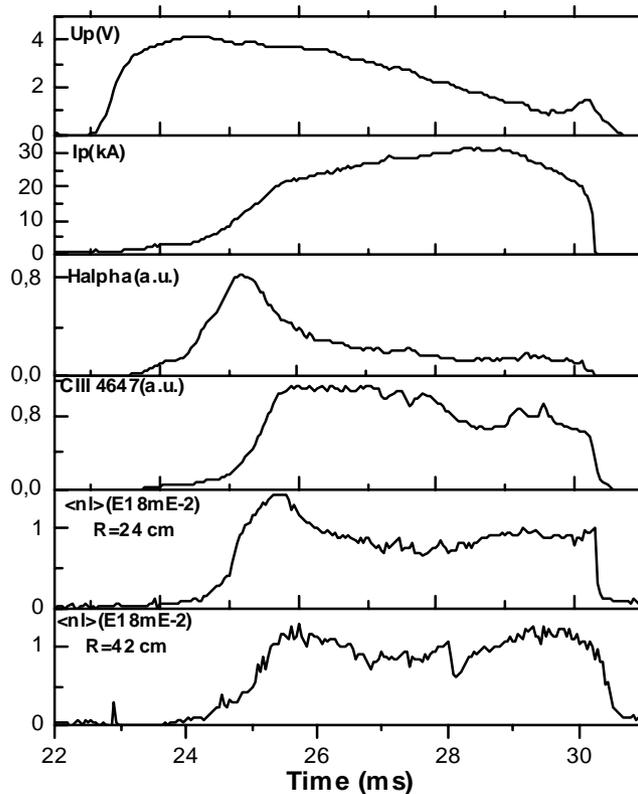


Fig.4. Time evolution of plasma parameters in a low toroidal magnetic field discharge. $I_{rod} = 200$ kA.

The central solenoid was energised in a single swing regime. The preprogrammed current up to 52 kA was generated by 70 kA thyristor rectifier. This value corresponds to 0.11 Wb magnetic flux in the solenoid and allows to achieve the plasma current of at least 0.2 MA. All the basic PF coils were also energised, including coils for plasma vertical and horizontal position feedback control.

The RF generator for plasma ion cyclotron heating is under construction at the Ioffe Institute. The generator has variable frequency in the range of 10 – 50 MHz. The RF power will exceed 1 MW, the pulse length ≤ 0.1 s. The antenna and the waveguide are almost prepared for installation on the tokamak.

Neutral beam injector was recently delivered to Ioffe Institute from TRINITI. The injector has the beam power of 0.5 – 1 MW at the beam energy about of 30 keV.

6. Acknowledgements

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References:

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solution of equations describing the evolution of plasma current and plasma energy. Alcator, Neo-Alcator and T-11 scalings for energy confinement time were used. The best coincidence of the measured and simulated waveforms of I_p was achieved under the assumption of by a factor of two enhanced confinement and the value of plasma effective charge with dominating carbon impurity in the range of $1.5 \leq Z_{eff} \leq 3$. Under these conditions the plasma volume averaged electron temperature $\langle T_e \rangle \sim 60$ eV, and the radiation losses do not exceed 10% of ohmic power.

5. Status of Full-Scale Plasma Experiment.

At present the commissioning of the basic power supplies and the control systems is going on. The toroidal magnetic field of 0.35 T at a radius $R = 0.36$ m was achieved.