

SCENARIO OF GLOBUS-M OPERATION IN OH REGIME.

N.V.Sakharov¹, A.S.Anan'ev¹, S.E.Bender², V.E.Golant¹, V.K.Gusev¹, A.V.Dech¹,
O.I.Konkov¹, Yu.A.Kostsov², E.A.Kuznetsov³, R.G.Levin¹, V.B.Minaev¹, A.B.Mineev²,
O.A.Minyaev¹, A.N.Novokhatskii¹, Yu.V.Petrov¹, E.N.Rumyantsev², V.N.Scherbitsky³,
E.I.Terukov¹, I.N.Trapeznikova¹, V.A.Yagnov³.

¹ - Ioffe Physico-Technical Institute, 26 Politekhnicheskaya, 194021, St.Petersburg, Russia

² - D.V.Efremov Institute, 196641, Metallostroy, St.Petersburg, Russia

³ - TRINITI, 142092, Moscow Region, Troitsk, Russia

Spherical tokamak Globus-M [1] (major radius $R=0.36$ m, minor radius $a=0.24$ m, aspect ratio $A=R/a=1.5$, plasma current up to 0.5 MA in toroidal magnetic field up to 0.6 T on axis, elongation up to 2.2, triangularity up to 0.4) was constructed at the Ioffe Institute, St.Petersburg. The full-scale experiments with Ohmic plasmas were started in the summer of 2000 after a commissioning of the basic power supplies – thyristor rectifiers of 125 MVA total power. The plasma current up to 0.25 MA was achieved in the toroidal magnetic field of 0.37 T at the radius of 0.36 m. The experimental range of vertical elongation is 1.1-1.9, and triangularity 0.1-0.4 in wall limited and double X-point magnetic configurations [2]. The experiments performed in 2001 were focused on the vacuum vessel conditioning after installation of graphite tiles, the study of the plasma shaping and plasma position feedback control and the optimization of the power supplies for a further improvement of the plasma discharge performance and the preparation of auxiliary heating experiments.

The first plasma experiments were performed in the vacuum vessel with a stainless steel first wall. The vessel conditioning technique included the bake-out at the temperature of 200⁰C, the He glow discharge cleaning (GDC) and the boronization. The required procedure of GDC appeared to be quite similar before and after installation of protective graphite tiles on the vessel inner cylinder and partly on the poloidal limiters. At least 10 hours of bake-out at 200⁰C and 40 hours of He GDC at a current of 1-2 A were necessary after the vessel opening to atmosphere. Also each experimental session is preceded by 3-4 hours of GDC.

The implemented boronization technique is described in [3]; its influence on the plasma parameters is described in [2]. The carboran $C_2B_{10}H_{12}$ was deposited on the vessel wall in the He glow discharge. The vessel was preheated at a temperature of 160⁰C. Two boronizations during one hour each were performed before the installation of graphite tiles, and then two shorter boronizations of 30 minutes each were made for the graphite limiter conditioning. In both cases the boronization led to 20% increase in plasma current and dramatic suppression of the hydrogen recycling.

The carboran film properties were studied at the Laboratory of Physical and Chemical Properties of Semiconductors of the Ioffe Institute. The carboran films of 1 μ m thickness were deposited on the silicon, quartz and glass plates in 40 MHz He or Ar glow discharge. The deposition rate increased at the substrate temperature rise in the range of 20⁰ – 100⁰C. The films of the amorphous structure had the B/C ratio about 48%/52%. The content of hydrogen reached 30% at the room temperature and could be reduced by annealing at 350⁰C. The carboran film electric properties are similar to semiconductors. The forbidden gap width

is about 4 eV, and the characteristic values of the specific resistance $\sim 10^6$ Ohm \times cm at a room temperature and $\sim 10^5$ Ohm \times cm at a temperature of 100⁰C. The films are transparent in the visible range. They are crack-free at the thickness less than 2 μ m. At the higher thickness cracks and the film off flaking were observed.

The position of the PF coils, the central solenoid and the vacuum vessel is shown in Fig.1. In the described plasma experiments the number of commissioned power supplies was insufficient for energizing of PF1 and PF2, designed for plasma shaping. The central

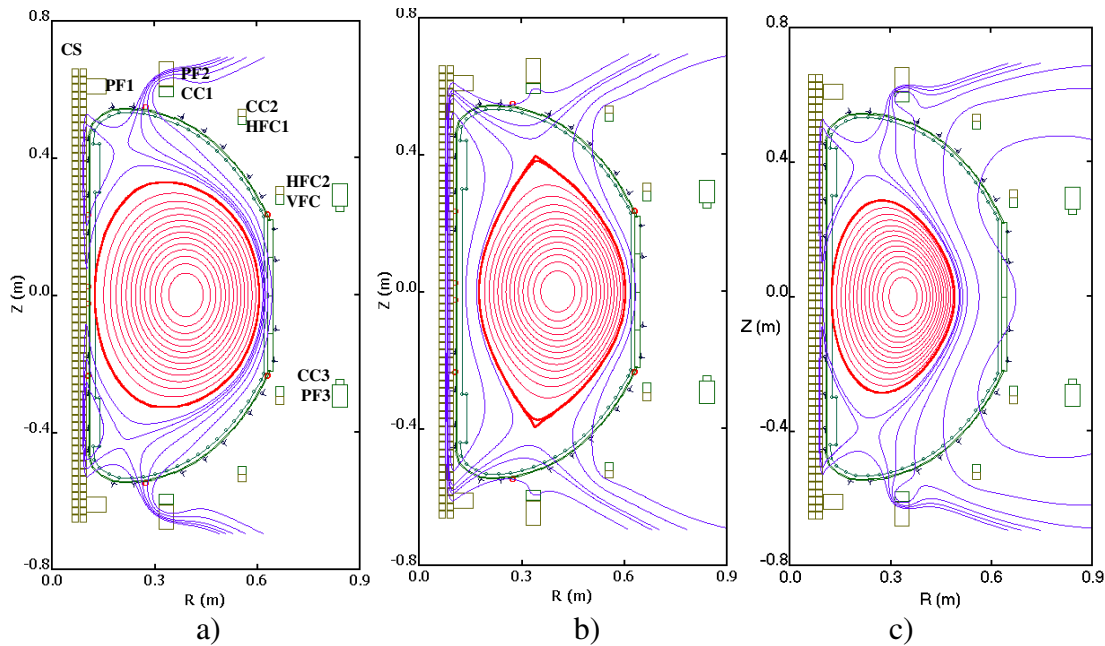


Fig.1. EFIT reconstructions of poloidal flux contours for various ratios of current in central solenoid and in CC.

a) inner wall limited, $k = 1.4$; b) double X-point, $k = 1.9$; c) 7 cm shifted to inner wall, $k=1.6$

solenoid operated in a preprogrammed single swing regime, and the solenoid stray field was used for variation of plasma vertical elongation. For this purpose, the preprogrammed current in the coils CC1-CC3 connected in series and designed for correction of the solenoid stray field was changed during plasma discharges, while the preprogrammed current in the solenoid remained the same. The equilibrium configurations in Fig.1 are the result of EFIT code [4] analysis between shots. The input data comprised signals of about 30 magnetic probes measuring components of the poloidal magnetic field near the plasma boundary, the plasma current, coil currents, plasma diamagnetic flux and toroidal current in the vacuum vessel. The plasma current was measured with the Rogowsky coil positioned inside the vacuum vessel. The second Rogowsky coil was placed outside the vessel and recorded the total toroidal current. The difference between two measured currents gives the current induced in the vessel walls (see Fig.2). The directly measured plasma current and EFIT reconstructed one coincide within the accuracy of 2-4%.

Fig.2.illustrates the scenario of Globus-M shot. The plasma current is generated during the ramp-up phase of the central solenoid current I_{CS} . The induced toroidal current in the vessel wall does not exceed 30-50 kA in the phase of plasma current ramp-up. The steady state current in the solenoid is sustained for the plasma current resistive dumping. The value

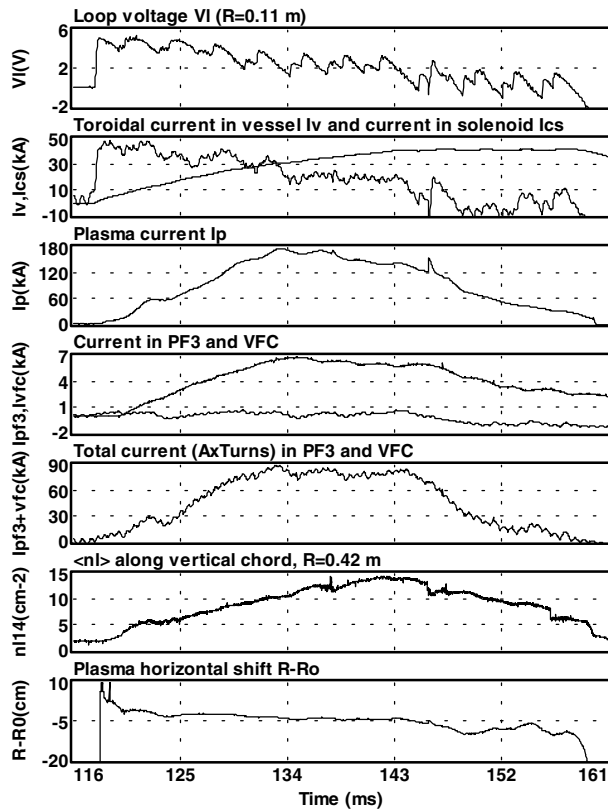


Fig.2. Time evolution of parameters in OH discharge, illustrating the scenario of Globus-M operation and the control of plasma horizontal position.

probes. The characteristic distance between the sensors and the plasma boundary is 2-4 cm in the mid-plane. The plasma radial shift $\Delta R = R - R_0$ is calculated from the center of the vessel toroidal axis $R_0 = 0.37$ m.

The VFC control the plasma radial shift according to the preprogrammed waveform. The PF3 energized by “slow” six-phase thyristor rectifier produce the main part of the vertical field. The principle of PF3 operation is to sustain current in VFC near zero level. During the discharge the control system can move the plasma column along the major radius. The magnetic configuration shifted to the inner wall is shown in Fig.1c.

The total current in PF3 and VFC in Fig.2 basically follows the waveform of the plasma current and also responds to the increase of the plasma density measured along the vertical chord positioned at the radius $R = 42$ cm. The external gas puffing provides the density control. The internal reconnection event (IRE) described in previous ST experiments [5] spontaneously occurs in the second half of the discharge and leads to the plasma radial displacement of ~ 3 cm towards the inner wall. The control system returns the plasma column to the initial position after a few milliseconds delay caused by a limited productivity of the presently utilized power supply.

of I_{CS} did not exceed 42 kA in the last experimental campaign, which corresponded to the magnetic flux of 0.1 Wb.

Plasma in Globus-M is confined within the vessel with the characteristic wall thickness of 2-3 mm and L/R time ~ 1 -2 ms. The nominal gap between the plasma outer boundary and the first wall is about 2-4 cm, which requires a careful monitoring of the plasma position by means of the feedback control system. The system is based on analog amplifiers and thyristor choppers with a frequency response up to 3 kHz. The choppers feed low inductance VFC for R-position control and two pairs connected in series HFC1 and HFC2 for Z-position control (see Fig.1). The input data for R-position control are the average magnetic flux measured by two saddle loops located below and above the mid-plane, and the poloidal field measured by two magnetic

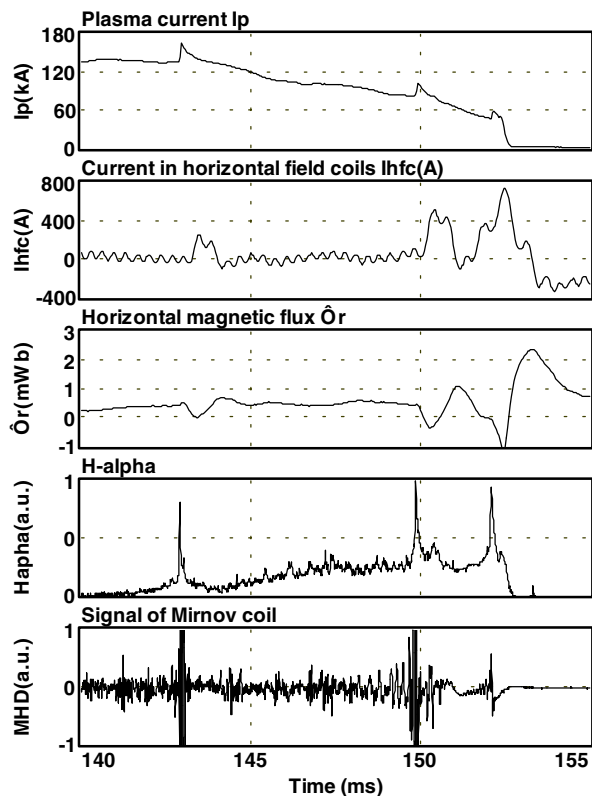


Fig.3. Plasma Z position control in the discharge with IREs.

The radial magnetic flux Φ_r measured by the two flux loops positioned on the vessel top and bottom domes at the radius $R = 0.28$ m is used as the input signal for the plasma Z-position control. The feedback system controls current in HFC in order to sustain Φ_r near zero level. Low elongated plasmas in Globus-M ($k \sim 1.2-1.5$) are mostly vertically stable even without the operating control system. Fig.3 shows the control system response to the IREs in the phase of plasma current termination. The estimated vertical shift corresponding to the Φ_r variation during the IREs does not exceed 1-2 cm. At higher values of elongation IREs could lead to termination of plasma discharges accompanied by the vertical displacements $\sim 6-10$ cm.

Achieved parameters and plans

The achieved range of plasma parameters comprises the plasma current up to 0.25 MA, the toroidal field in the range of 0.07-0.38 T, the plasma pulse length up to 60 ms, the vertical elongation of 1.1-1.9, the triangularity of 0.1-0.4, the safety factor $q_{95} \geq 2.1$, the minimum $q_{cyl} \sim 0.9$.

The power supply upgrade was performed in parallel with plasma experiments. All the existed thyristor rectifiers have been prepared for the next experimental campaign. Two 32 MVA rectifiers were connected in parallel and utilized for energizing of TF coils. As a result, the TF rod current about 1 MA ($B_T = 0.55$ T at $R = 0.36$ m) was achieved. Two other high power rectifiers were tested for a subsequent ± 70 kA current swing in the central solenoid. Eight additional turns were wound in-situ in each PF3, and thus the productivity of the plasma radial position control system was increased. PF1 and PF2 will be utilized for plasma shaping. Digital control of plasma position is planned at the end of 2001.

Acknowledgements

This work was supported by ISTC, RF Ministry of Industry, Science and Technology, IAEA grant and RFBR grants 00-02-16934 and 01-02-17882.

References

- [1] Gusev V.K., *et al.*, Technical Physics, v.44, No.9, 1054, 1999
- [2] V.K.Gusev, *et al.*, Nuclear Fusion **41** (2001), No.7
- [3] V.M.Sharapov, *et al.*, Journal of Nuclear Materials 220-222 (1995), pp.730-735.
- [4] L.L.Lao, *et al.*, Nucl. Fusion **25** (1985) 1611.
- [5] A.Sykes, *et al.*, Nucl. Fusion **32** (1992) 694.