Globus-M2 Design Peculiarities and Status of the Tokamak Upgrade

V.B. Minaev[1], V.K. Gusev[1], M.I. Patrov[1], N.V. Sakharov[1], V.I. Varfolomeev[1], E.N. Bondarchuk[2], A.K. Cherdakov[2], A.A. Kavin[2], M.V. Khokhlov[2], S.V. Krasnov[2], A.N. Labusov[2], V.V. Mikov[3], V.N. Tanchuk[2], A.A. Voronova[2], E.G. Zhilin[4]

[1)] *Ioffe Physical-Technical Institute of the Russian Academy of Sciences, Saint Petersburg, Russia*
[2)] *JSC «D.V. Efremov Institute of Electrophysical Apparatus», Saint Petersburg, Russia*
[3)] *JSC INTEKHMASH, Saint Petersburg, Russia*
[4)] *Ioffe Fusion Technology Ltd., Saint Petersburg, Russia*

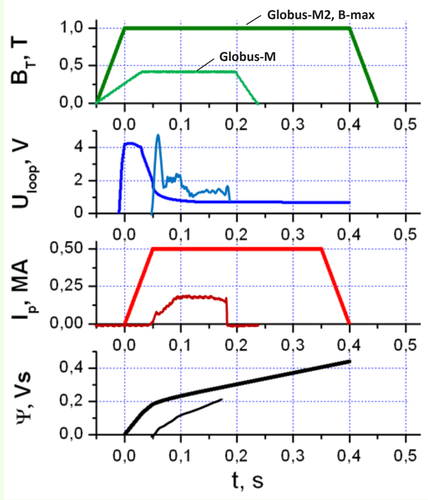
Abstract. The Globus-M spherical tokamak has demonstrated practically all of the project objectives. The increasing of the magnetic field up to 1.0 T together with the plasma current up to 0.5 MA should significantly enhance plasma performance in Globus-M2 machine. Simultaneously it will entail serious rise in loads on the magnetic system in the upgraded tokamak. Thereupon a review of the design was developed. The vacuum vessel remains the same in order to reduce the project cost. Results of the complete 3-D finite element model thermal and stress analysis are presented for the novel magnetic system. The mechanical strength was enhanced significantly. Radius of the toroidal field coil outer limb was enlarged slightly in order to reduce field ripple. The central column and the toroidal field coil joints were fully redesigned. Final design of the tokamak upgrade is discussed in the report as well as current status of the work.

Key Points of the Tokamak Upgrade

- **Design of the magnetic system and supporting structure is substantially revised in order to increase the toroidal magnetic field up to 1.0 T together with the plasma current up to 0.5 MA .**
- **Vacuum vessel, in-vessel components and diagnostics remain the same. That allows reducing project costs.**

Basic plasma shot scenarios

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 (at a=0.24 m)	0.5 MA (at a=0.24 m)
Poloidal flux consumption	0.4 Wb (+/- 0.2 Wb)	0.4 Wb (+/- 0.2 Wb)
Duration of TF flattop	≤ 0.4 s	≤ 0.7 s
Basic regime	Inductive	Inductive / Non-inductive CD
TF field rippling at R=0.6m	≤ 0.4%	≤ 0.4%
Number of working pulses in regime with maximal load	5000	10000
Minimal pulse repetition rate	Every 15 min	Every 15 min

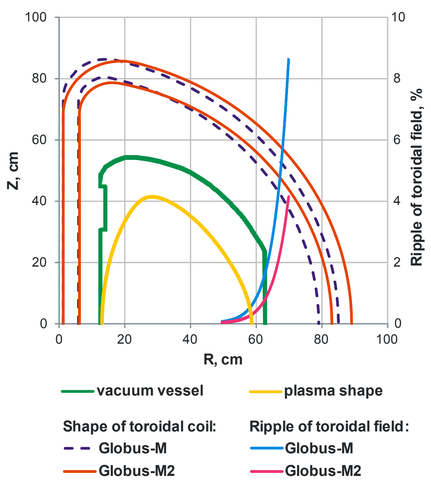


Plasma scenarios were developed with the help of routine IPB98(y,2) scaling using Globus-M experimental database.

Current in TF coil reaches 110 kA, that is equal to 1.76 MA of total current in TF rod for "B-max" regime.

For Globus-M these currents were equal to 44 kA and 0.7 MA correspondently.

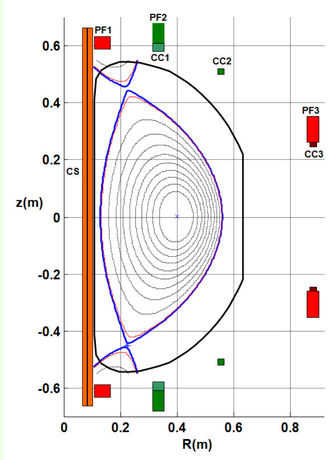
- Novel design of TF coil is required as well as power supply upgrade.



In Globus-M2 toroidal field ripple near plasma boundary will be reduced approximately by a factor of 2.

In **Globus-M** the TF ripple near plasma boundary is sufficiently high (0.6–0.8%). In **Globus-M2** the radius of TF coil outer limb will be increased from **800 mm** to **840 mm**.

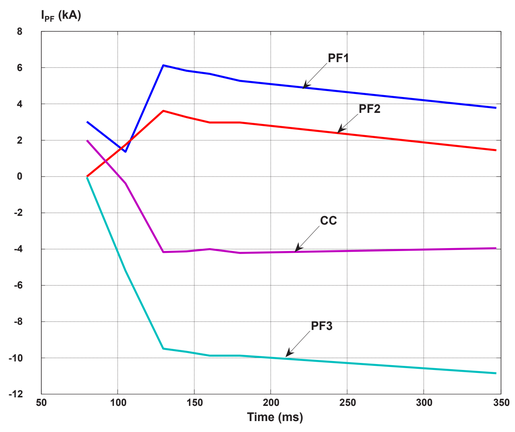
- The increase of TF coils overall diameter requires manufacture of two pairs of outer PF coils (PF1, PF3). Nevertheless, their coordinates remain practically unchanged, which allows keeping the full set of plasma magnetic configurations available in Globus-M.



I_p=0.5 MA, κ=2

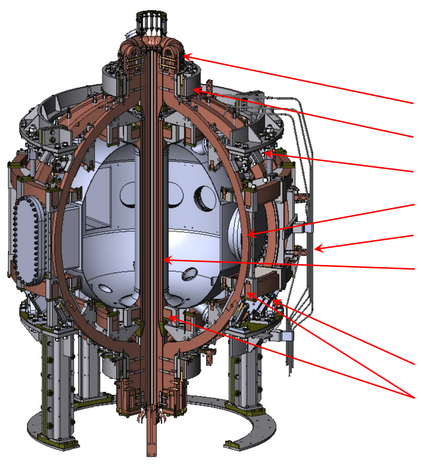
Magnetic equilibrium of 0.5 MA plasma set requirements for PF coil currents.

- Currents in PF coils are compatible with existing thyristor rectifiers.
- ± 70 kA current swing in new central solenoid requires power supply upgrade in order to increase the output voltage.



Design description

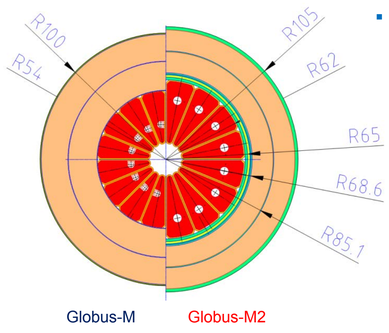
Globus-M2 design differs from Globus-M one in significant details.



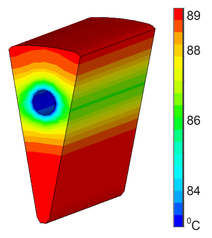
- Flexible bas bars are placed outside of the maximal stresses zone.
- Bandage rings bear higher thermal and mechanical loads.
- Upper supporting ring and 4 load-bearing crosspieces are added.
- TF coil limbs are made of high grade copper ($б_{02}$ > 220 MPa).
- Water cooling is applied to all poloidal field coils.
- Central Column is redesigned completely. CS is wound in two layers in situ around the TF coil inner rod with a thin gap. The temper hard copper conductor ($б_{02}$ > 290 MPa) of trapezoidal cross-section is used.
- Support structure is redesigned.
- PF1 and PF3 coils are redesigned.

Central column arrangement was optimized with the help of thermal analysis.

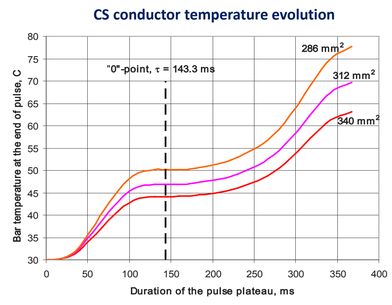
- The conducting area of TF coil inner segments is increased whereas the solenoid conductor cross-section is decreased (20×15 mm² vs 20×20 mm²).
- The gap of 10 mm between the column and the vessel inner cylinder in Globus-M allows an increase of the total column diameter in Globus-M2 reducing the gap value to approximately 3 mm.

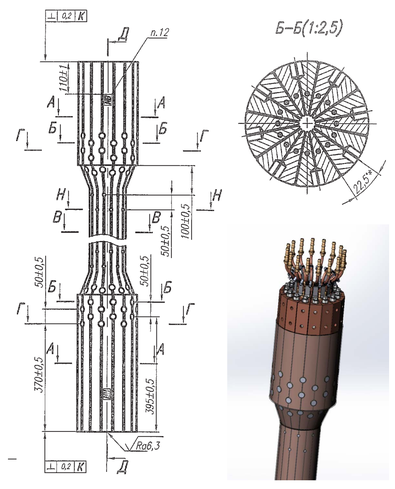


TF coil segment temperature distribution in the end of current pulse. Starting value is 30°C



CS conductor temperature evolution

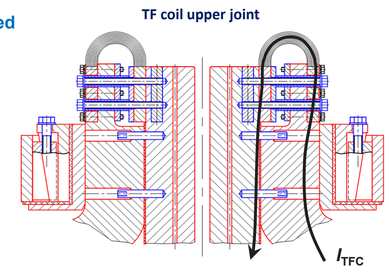




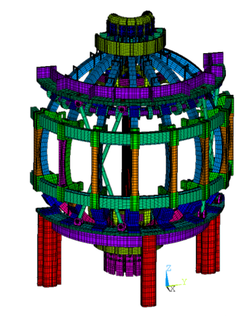
TF coil central rod design.

- 16 inner segments are assembled as a single whole rod.
- Cold extruded copper ($б_{02}$ > 240 MPa) is used.
- Segments are insulated with prepreg.
- In order to withstand shear stresses TF coil rod is enhanced with insulated dowels inserted between segments.
- Adequate thermal conditions are provided by the continuous water cooling.
- Electric contacts are unloaded mechanically.

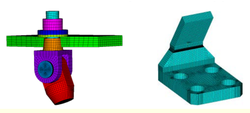
TF coil upper joint



Globus-M2 FE model

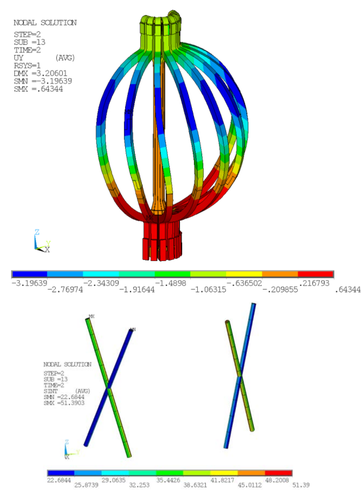


Submodelling technique was used for the detailed stress analysis of the supports.



The complete 3D finite element model was developed and applied for mechanical and thermal stress analysis.

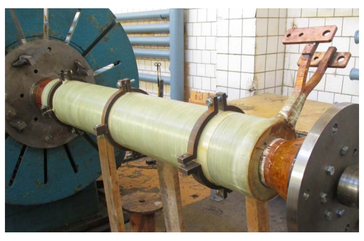
- Maximal displacement of the TF coil in toroidal direction does not exceed 3.2 mm under the highest possible operation loads ("B-max" regime, disruption at the end of TF plateau).
- Special load-bearing crosspieces undergo a pulling force of 43.5 kN and compressing one up to 26.5 kN (safety margin for buckling for the unit is equal to 4.25).
- The operating limit of the upgraded tokamak is estimated as 30000 shots, including at least 5000 shots with maximal values of the toroidal magnetic field and plasma current.



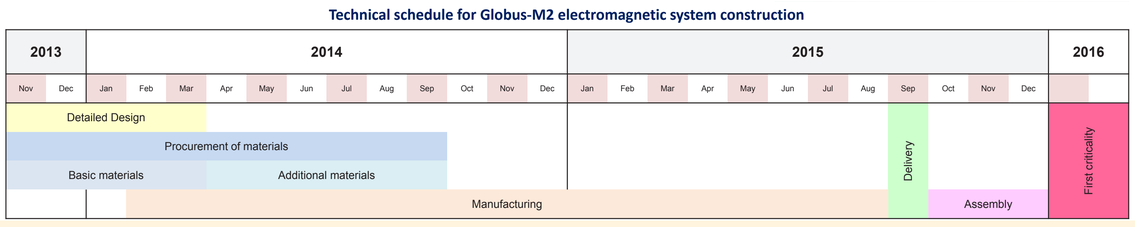
Current Status of the Tokamak Upgrade

Globus-M2 magnetic system will be constructed by the end of 2015.

- ✓ The detailed design of tokamak upgrade has been completed.
- ✓ All special conductors for the TF rod, TF coil outer limbs, PF coils and central solenoid have been manufactured and delivered to the Ioffe Institute.
- ✓ Prototypes of insulated dowel joints of TF inner rod were manufactured and successfully tested.
- ✓ A full-scale prototype of central solenoid coil was wound in situ over TF coil central rod mockup with a 1 mm gap. The original conductor was used. The developed technique provided mechanical detachment between CS and TF coil.



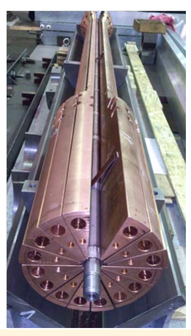
Technical schedule for Globus-M2 electromagnetic system construction



Manufacturing of new magnetic system was started successfully in the beginning of 2014.

- ✓ Half-finished material for the TF rod was manufactured at KME Germany GmbH & Co. KG by order of IFT Ltd.
- ✓ Workpieces for TF coil outer limbs and conductors for PF coils and CS were manufactured by Luvata Pori Oy, Finland and shipped to the Ioffe Institute site.

- ✓ Inner segments of the TF coil were machined and preassembled by JSC "INTECHMASH".



- ✓ Wedges for the TF coil central rod were treated by means of bead blasting , insulated with preprag, and assembled by JSC "NIIEFA". Insulated dowels will be installed between wedges before baking.

This report employs the results, which have been obtained with the help of the unique scientific device spherical tokamak Globus-M. This work is financially supported by the Ministry of education and science of Russia. The unique ID of the project is RFMEFI61914X0001.

Contacts:

Vladimir.Minaev@mail.ioffe.ru, Vasily.Gusev@mail.ioffe.ru

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