

STATUS OF SPHERICAL TOKAMAK GLOBUS - M

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1. Introduction

Spherical tokamaks are characterized with significantly lower aspect ratio (ratio of major to minor radii of plasma column: $A = R/a$) compared to conventional tokamaks. The unique features of spherical tokamaks, i.e. high plasma pressure in low magnetic field, good energy confinement in moderate size plasma, high fraction of selfgenerated (bootstrap, diamagnetic etc.) currents, dispersed heat and particle fluxes in scrape of layer should be experimentally realized to reach high fusion power density at low cost. Outstanding experimental results achieved at START [1] in demonstrating high beta toroidal invoked the development of international program on investigation of fundamental plasma properties in low aspect ratio configurations.

Globus-M together with new generation of machines is nominated for the spherical tokamak proof of principals and establishing the comprehensive experimental data base.

Description of the design details, machine control, plasma parameters simulations, etc. can be found in [2,3]. This paper is devoted to the discussion of individual project features, experimental program details and current status of the project.

2. Individual features and link to other spherical tokamak projects

In spite of being relatively old design machine - the conceptual design was basically completed in 1994 - Globus-M tokamak has bright individual features. Globus-M is spherical tokamak ($A = 1.5$) of small size (major radius $R = 0.36$ m, minor radius $a = 0.24$ m), but of relatively high current and magnetic field ($I_p = 0.5$ MA, $B = 0.65$ T). Small geometrical size results in higher current density and higher B/R ratio compared to other spherical tokamaks under construction which leads to very high absolute density limits, $n_{lim} \sim 2 \times 10^{20} \text{ m}^{-3}$. Other distinguishing feature of the machine is close fitting vacuum vessel comparatively to other spherical tokamaks which increases the vessel stabilizing effect to vertical plasma column movement as well as to low n kink modes, but requires accurate vessel wall conditioning and fully automatic plasma column position/shape feedback control.

Fig.1 illustrates the discharge conditions for a few existing and being under construction spherical tokamaks in terms of plasma current versus pulse duration time. It should be noted that Globus-M has sufficiently long pulse duration in comparison to existing spherical tokamaks that ensures quasistationary discharge conditions. High current and magnetic field require high power consumption which is ensured by the feedback controlled power supplies connected to the national power grid providing good credit for further pulse duration increase.

Wide aperture equatorial plane ports of vacuum vessel and specially designed ports disposed at big poloidal angle (72°) provide good conditions for housing RF antennas of ICR, HHFW and “lower hybrid” range heating and CD schemes. Auxiliary heating and CD methods to be used are capable of local and global current density and plasma pressure profiles modification to achieve high β_T , high density and noninductively driven current regimes.

Advanced diagnostics set for detailed plasma parameter profile measurements provides conditions for investigation of stability and transport plasma properties. It consists of multipoint/multipulse Thomson scattering system, pulse radar reflectometer, multidiode SXR pin holes cameras with spectroscopic possibilities and high resolution/high speed videocamera. This set complements routine diagnostic equipment magnetic loop and probe arrays, HXR monitoring, HCN interferometer, visible and UV spectroscopy, etc. and create conditions for necessary experimental data single pulse recording and processing.

3. Experimental program details

Experimental program is focused on the experimental prove of the basic spherical tokamak advantages as well as basic physics research of plasma in spherical tokamak geometry. Few steps from the machine shake down to the high beta, high density, high noninductive current regimes realization are envisaged.

Program starts with ohmic heating regime optimization from preionization and start up to the fully feedback controlled plasma column with high elongation ($k \leq 2.2$) and triangularity ($\delta > 0.2$). Together with feedback control of plasma current, column position and shape which plays a key role in achieving stable, reproducible, low Z_{eff} discharge conditions important is the power and particle fluxes handling at the plasma periphery.

The design of Globus-M tokamak permits the quick access to segmented protection (8 elements) and divertor plates (8 upper and 8 lower elements) and their fast reassemble. Three millimeter thickness stainless steel elements could be exchanged and plated at the special facility with low Z_{eff} plasma facing materials to achieve better machine performance. The technology available permits to deposit uniform surface layers of Be (~ 1 mm), B and C (~ 0.1 mm). The same refers to the protection of the RF antenna elements from their interaction with plasma fluxes.

Second step is achieving high plasma parameters with the help of auxiliary heating. Two methods of RF heating will be used. Fundamental ion cyclotron resonance in hydrogen minority scenario at the frequency range $f = 10 \div 14$ MHz and power level $0.5 \div 2$ MW will be used for the plasma heating. Simulations in cylindrical geometry slab model taking into account strong toroidicity together with magnetic shear effects show rather narrow power deposition profile for fast magnetosonic wave at $f = 11$ MHz, with relatively good absorption efficiency, see Fig. 2. High harmonic fast wave heating proposed by M.Ono [4] is effective mechanism for electrons heating in spherical tokamak conditions. Frequency range $f = 30 \div 50$ MHz and power level of about 1 MW are planned for experiments in Globus-M. The frequency range of $f \approx 80$ MHz is under discussion now which should provide better heating conditions with more narrow deposition profile.

Heating and CD at the frequency $f = 2.45$ GHz which is about 8-10 times higher Globus-M lower hybrid frequency provide much better accessibility conditions even for the waves with relatively small parallel refractive index. Such waves could be launched either from high poloidal angle grill position ($\theta \approx 72^\circ$), or from equatorial plane, with waves slowing down in poloidal direction. Simulations show that power deposition zone is narrow with radial position dependent on plasma current [5]. The higher current moves power deposition zone from plasma periphery towards center. First results encourage us to use this method for local control of current density and plasma pressure profiles.

Low ballast volume of vacuum vessel (close fitting vessel design) together with high aperture ports make possible the injection of neutral particle beam for plasma heating and CD. Reduced charge exchange losses of the beam power should increase the heating efficiency. Simulations of orbits and confinement of high energetic particles are necessary.

4. Current status of the project

At the end of the first half of 1998 all the machine parts have been manufactured. The tokamak assembly started at the beginning of May 1998. High quality and accuracy of parts manufacturing together with minimum errors in the machine design ensures the quick machine assembly. At the end of June 80% of the tokamak parts are assembled. The assembly will be completed in July 1998. The overall view of current tokamak assembly is shown in Fig. 3. The in-vessel components (divertor plates and protection plates) view is shown in Fig. 4. After the assembly the tokamak, as a whole unit (overall weight of the machine ~ 5.5 ton), will be transported to new experimental machine hall built at Ioffe institute. The installation of the tokamak to the basis stand which is under assembly now is scheduled for August 1998. The connection to the vacuum pumping system (commissioned), cooling system (under construction), power feeders (under assembly), control system (first turn is commissioned) together with power supply tests is scheduled for September - November 1998. Important break-through was achieved this year in repair and maintenance of high power high voltage equipment of Globus-M power supply substation (125 MVA step down grid transformer 110/10 kV and open air distributor device 110 kV). The equipment will be energized and commissioned in July 1998. Tokamak shake down is planned at the end of the year 1998.

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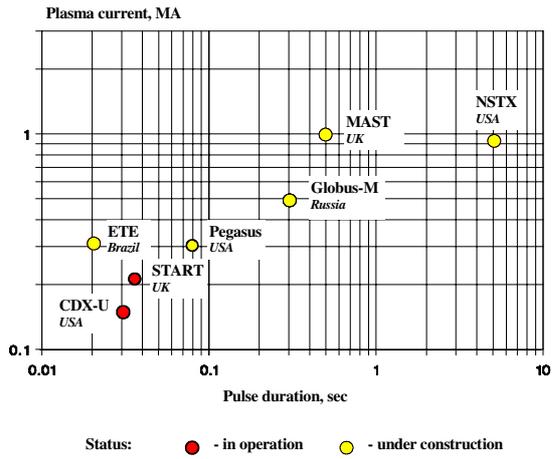


Fig. 1. Current vs. discharge pulse duration diagram for selected spherical tokamaks.

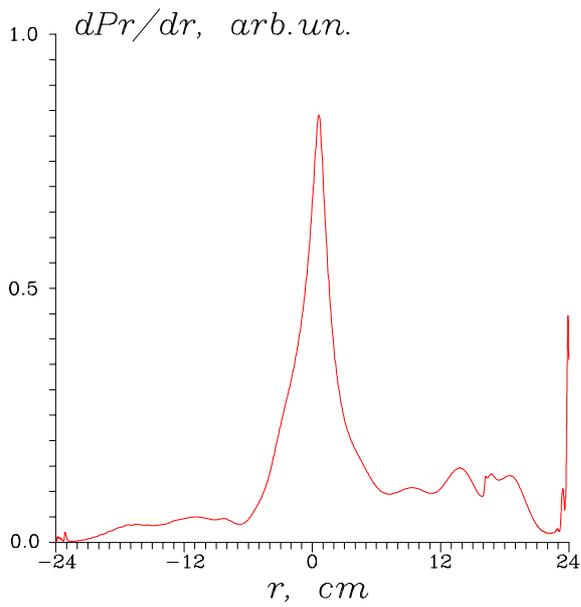


Fig. 2. Power deposition profile for a single RF antenna of 18 cm width at 11 Mhz.



Fig. 3. View of Globus-M assembly. June 22, 1998



Fig. 4. Divertor and protection in-vessel plates. Picture is taken through vacuum vessel high aperture port.