Fast scanning probe for the Globus-M2 tokamak

V A Tokarev¹,², V K Gusev¹, N A Khromov¹, M I Patrov¹, Yu V Petrov¹, N V Sakharov¹, V B Minaev¹, V I Varfolomeev¹, A Yu Telnova¹, P B Shegolev¹, N N Bakharev¹, G S Kurskiev¹, E O Kiselev¹

¹ Ioffe Institute, Saint-Petersburg, Russia
¹,² E-mail: Valentin.tokarev@ioffe.mail.ru

Abstract. A fast scanning probe which can penetrate inside the separatrix during discharge was developed for Globus-M2. The probe has been designed to move various sensor pins into the scrape-off layer. The driving force is provided by a crank-slider mechanism which is ensured maximum linear speed about 4 m/s. The paper presents probe head and drive system description.

1. Introduction

Understanding of physical processes in the scrape-off layer (SOL) of tokamaks is important since their performance is limited by the heat loads on the plasma-facing components. Also measurements of plasma edge parameters could help in clarification of turbulence and anomalous radial particle transport in boundary plasmas [1].

Electrical probes are one of the diagnostics, which is successfully used for measurements on plasma edge. [2]. Since the 80s of the last century [3], so-called ‘fast scanning probes’, have become widely employed on tokamaks. The main advantage of them is an opportunity to obtain profiles of plasma parameters with a rather high spatial resolution during discharge. Also using this diagnostics is minimizes the plasma perturbations and damages of the probe head itself [4].

An important part of such devices is a driving mechanism, which is responsible for their movement. For example, pneumatic cylinders are used as drives on TEXTOR [5], D-IIID [6] and NSTX [3] tokamaks. Magnetic drive is used on Hanbit machine [6]. Pneumatic systems have typical the probe input time into the plasma of about 50–100 ms, and a penetration distance inside boundary plasma is about ~ 10 cm.

In this work we present fast scanning probe, with a crank-shaft mechanism as a drive, developed for the Globus-M2 tokamak.

2. Design considerations

Globus-M2 is a spherical tokamak [8, 9] with the minor radius a=0.24 m, the major radius R=0.36 m, a toroidal magnetic field BT≤1.0 T, the plasma current Ip≤0.5 MA and a divertor plasma configuration. Taking into account modeling of Globus-M2 edge [10], the design requirements can be summarized as:

(1) ability to obtain several plasma parameters: electron temperature Te(r), electron density ne(r), Mach number M(r), radial and poloidal electric fields Er(r) and Eθ(r),
(2) covering of the needed dynamic range plasma parameters: Te ≈ 3–75 eV, ne≈(0.1–6)∙10¹⁹ m⁻³,
(3) probe head and pins have to withstand a heat flux of 100 MW/m² during 15 ms,
be made of low Z materials to avoid a plasma contamination by heavy impurities,
(5) it should provide minimum 2 ‘jumps’ during stationary phase of discharge,
(6) probe components should be easily accessed for maintenance,
(7) withstand to accelerations of up to ~ 50g which allows to reach maximum linear velocity 4 m/s.

Achievement of the above mentioned tasks can be divided into two parts: firstly, it was necessary to develop a probe head that would meet requirements. Secondly it had to establish a driver that provides the required parameters for the movement of the probe during discharge.

3. Nine-pin probe head
In Fig 1 the probe head structure is shown. Cylindrical part is protected against high heat fluxes by a graphite shield. The pin head is made of Boron Nitride insulator, with graphite pins and is used for measurements of plasma parameters. All electrodes spread out 1.5 mm above the insulator surface.

The modular design of the head is implemented as follows: molybdenum electrical contacts are placed in the intermediate insulator (Fig. 1 (4)), and then graphite electrodes are fixed in it by means of a threaded connection. Thus, a tight connection with the electrical contacts, to which the wires located inside the rod’s connector is provided (Fig. 1 (7)). The tongue-and-groove construction of the probe head parts allows us attaching the insulator elements and rod’s connector. This construction, as a whole, is screwed into a graphite shield of 10 cm length.

The diameter of graphite electrodes is 1.6 mm, five of them (Single, Isat, V+, Vf1, Vf2) are located on the 1.5 mm ledge. In the basic configuration of pins, the Isat, Vf2, V+ form a triple probe for measuring the electron temperature and density, and Mach1, Mach2 form the Mach probe [11]. A Single electrode is used to obtain the current–voltage characteristic. Two, poloidally separated pins Vf1 and Vf2 are floating to measure the floating potential and the poloidal electric field, pins Vf3 and Vf4 are also floating and displaced 1.5 mm radially from Vf2 to measure the radial electric field, taking into account electron temperature.

4. Probe driving mechanism
The fast scanning probe is placed in the midplane from the low field side of the tokamak. Construction of it is shown in Fig. 2. The lead screw assembly (stroke length = 57 cm) sends the probe to a stand-by position where it is close to the plasma, but not exposed to it.

The crank-slider mechanism is placed inside the vacuum chamber with two flanges, providing access during probe assembling. To transfer rotational motion from atmosphere into vacuum we use the ferro-magnetic fluid rotary feedthrough – KLFDTM12M25 of a thread mount solid shaft type[12].
The motion of the probe head during discharge is as follows: the one second before discharge beginning, signal from computer is fed on ac motor drive VFD-EL [13], which supplies voltage to electric motor ‘AIR 80V2’ transmitting rotation to a train of gears. The train of gears drives rotary feedthrough and it translates rotary motion to the crank-slider mechanism, transforming rotational motion into reciprocating motion. The rod of the probe drive moves inside the guiding tube, where two slider bearings and separators are placed (see Fig. 3a). The slider bearings are manufactured from aluminum with zirconium dioxide coating [14].

Usage of a crank-slider mechanism requires balancing, since the inertial forces acting on the rod of the probe drive are rather significant (see Fig. 3c). The most dangerous forces act across the rod, they can lead to its breakage, stopping of the movement and wear of the sliding bearings. The chosen counterweight allows one to minimize force of inertia across the rod (see Fig. 3b). To reduce friction of bearings and separators with the rod the dry lubricant EFELE AF-511, suitable for operation at the vacuum pressure 10⁻⁸ Torr, is used.

Position, velocity, and acceleration of the probe obtained at the 20 Hz frequency of rotation are shown in Figure 4. This frequency is the standard one and corresponds to the maximum linear velocity of 4 m/s. The distance of the probe movement is 6 cm, determined by the radius of the crank, which is 3 cm. This distance is enough for the probe penetration inside the separatrix under the conditions of the Globus-M2 tokamak [10]. All-ceramic bearings made of zirconium dioxide are used as rolling bearings in the crank-slider mechanism.

A position of the probe is measured with the help of an optical registration system is based on the Komoloff S-6 laser. 12 holes are made in the gear, connected with the rotary feedthrough, at the same distance along the entire circumference. Eleven of them have a diameter of 2 mm, and the last one of 3 mm. The laser module and the photodiode amplifier are mounted on a special bracket to the rotary feedthrough so that the laser beam passing through the gear holes falls on the photodiode.
A trapezoidal pulse sequence is obtained from the amplifier, thus ensuring determination of the probe position.

\[ \text{Figure 4. (a) Kinematics of the crank-slider mechanism. Position of the probe 0.06 m corresponds to location of the probe head maximum extended inside the tokamak, (b) Construction of the crank-slider mechanism.} \]

5. **Probe head tests**

In the last experimental campaign, a movable Langmuir probe was installed in the midplane from the low field side of the Globus-M tokamak [15, 16]. This probe was equipped with the same probe head as the fast scanning probe and suitable operation of it was demonstrated: profiles of $T_e$, $n_e$, $V_f$, $M_\parallel$, were determined. Also the preliminary experiments, to identify geodesic acoustic mode (GAM) were carried out based on floating potential signal. These observations were performed with the probe head position approximately 6 mm inside the separatrix and it successfully survived under conditions of considerable thermal loads. As a result of these measurements, it was shown that, in the Globus-M tokamak, the frequency of GAM oscillations is in good agreement with simple estimation [15].

6. **Conclusion**

The fast scanning probe with the crank-slider mechanism as a probe drive for Globus-M2 has been developed and manufactured. The probe operation rotation frequency is 20 Hz, which corresponds to a maximum linear velocity=4 m/s. The nine-pin probe head was successfully tested in the experiments on the Globus-M tokamak.

**Acknowledgments**

The work was performed on the Unique Scientific Facility "Spherical tokamak Globus-M", which is incorporated in the Federal Joint Research Center "Material science and characterization in advanced technology". The maintenance of tokamak was supported by the Ioffe Institute.

**Reference**

[1] Boedo J A et al 1998 Rev. Sci. Instrum. 69, 2663–70
[2] Matthews G F 1994 Plasma Phys. Control. Fusion 36 1595–28
[3] Boedo J A 2009 Rev. Sci. Instrum. 80, 123506
[4] Zhang W 2010 Rev. Sci. Instrum. 81, 113501
[5] Emmoth B 2003 et al. J. Nuc. Mater. 313–316 pp 729–33
[6] Watkins J G et al 1993 Rev. Sci. Instrum. 63 (10) pp 4727–30
[7] Bak J G et al 2000 Rev. Sci. Instrum., 71 (5) 2071-6
[8] V.K. Gusev et al 2013 Nuc. Fusion, 53 (9), p. 093013
[9] Minaev V B et al 2017 Nuc. Fusion 57 (6) 066047
[10] Sorokina D S et al 2018 Phys. Plasmas 25 (12), 122514
[11] Hutchinson I H, Chung K–S 1991 Phys. Fluids B 3 (11) 3053–8
[12] Solid Shaft Ferro-Magnetic Fluid Rotary Feedthroughs. (2019, April 12). Retrieved from https://www.lesker.com/newweb/sample_manipulation/rotarydrives_KJLC_ferrofluidsolutions idea_4_metric.cfm

[13] VFD-EL user manual. (2019, April 12). Retrieved from http://www.deltronics.ru/images/manual/VFD-EL_UM_EN_20160308.pdf

[14] Ceramic Closed Linear Bearings. (2019, April 12). Retrieved from https://www.automotioncomponents.co.uk/media/files/datasheet/L1764-ceramic-closed-linear-bushings.pdf

[15] Tokarev V A et al 2017 J. Phys.: Conf. Ser. 1094 012003

[16] Bakharev N N et al 2018 Nuc. Fusion 58 (12) 126029