FEATURES OF THE UPGRADED MAGNETIC DIAGNOSTICS APPLICATION IN THE U-2M TORSATRON

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Modernized magnetic sensor systems have been developed and tested to carry out the magnetic measurements on the U-2M torsatron. The effect of the metallic environment, high-frequency noise and the instability of the external magnetic field in the U-2M torsatron on the readings of magnetic sensors recorded during plasma experiments were studied.

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INTRODUCTION

Magnetic measurements in stellarator-type magnetic traps allow one to determine a number of important plasma parameters, such as the longitudinal plasma current, the Pfirsch-Schlüter currents, the plasma energy content, the shift and deformation of magnetic surfaces, the magnetic island structure; the plasma MHD activity, etc [1-4].

At present, modernized magnetic sensor systems and recording equipment are developed, fabricated and tested to carry out the research program on the U-2M torsatron [5]. These sensors allow to perform magnetic measurements under conditions observed in torsatron U-2M during plasma experiments on plasma RF heating and RF conditioning of walls of the torsatron vacuum chamber.

DEVELOPMENT AND TESTING OF THE UPGRADED MAGNETIC DIAGNOSTICS FOR TORSATRON URAGAN U-2M

Two diamagnetic loops covering different areas and located in one section of the torus and a Rogowski coil will be used to register variations of the toroidal and poloidal magnetic fluxes, respectively. To register variations of the zero, first and second harmonics of the poloidal magnetic flux, a set of 14 Mirnov coils placed in one cross-section of the torus will be used. Magnetic sensors will allow to detect changes of magnetic field in the frequency range from 10 Hz up to 200 kHz. The measurement technique is described in detail in the works [6, 7].

The value of Pfirsch-Schlüter currents, the presence of magnetic islands, the shift of magnetic surfaces, the structure of MHD-fluctuations, corresponding to the first harmonic will be determined by registration of variations of the first and zero harmonics of the poloidal magnetic field. The registration of variations in the second poloidal magnetic field harmonic also enables one to determine the presence of magnetic islands, the deformation of magnetic surfaces, and the structure of MHD-fluctuations with second azimuthal harmonics. The registration of toroidal magnetic flux variations and variations in zero harmonic of the poloidal magnetic field generated by the longitudinal plasma current makes it possible to determine the plasma energy content Γ based on the following expression:

$$\Gamma = \underbrace{\frac{B_0 R}{2}\Delta\Phi}_{(I)} - \underbrace{\frac{2\pi I^2 R}{c}}_{(II)} - \underbrace{\frac{2\pi B_0}{c}\int_0^a j_0 \frac{\partial}{\partial r}\left[r^2\int_0^r \iota_{st}\,dx\right]dr}_{(III)}, \quad (1)$$

where B_0 – is the magnetic field induction on the axis, j_0 – is the longitudinal current density; a – is the small plasma radius; R – is the major plasma radius; c – is the light velocity; P – is the gas-kinetic plasma pressure and ι_{st} – is the rotational transformation angle created by the stellarator field; $I = 2\pi\int_0^a j_0 r dr$ – is the longitudinal plasma current measured by Rogowski coil. Term (I) in expression (1) is related with the diamagnetic flux change ΔΦ, term (II) is the tokamak term related with the longitudinal current I in the plasma, term (III) is determined by the interaction between the longitudinal plasma current and the helical magnetic field described by the rotational transformation angle ι_{st} ("stellarator effect").

Fig. 1 shows temporal behavior of diamagnetic signal and plasma energy content calculated based on expression (1) and electrical measurements of diamagnetic signals during plasma experiments performed earlier. As can be seen from the Figure, an external pickup is observed against the background of a useful signal from a diamagnetic sensor, caused by a much slower instability of the external magnetic field. High-frequency interference is successfully suppressed by high-frequency filters and electronic integrators.

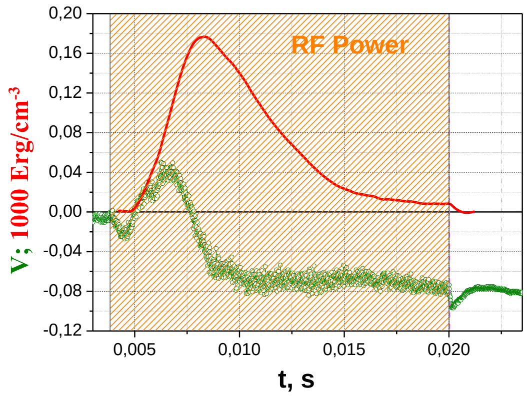


Fig. 1. The temporal behavior of the diamagnetic signal (shown in green), as well as the energy content of the plasma (shown in red) during plasma experiments on the U-2M torsatron in early 2014

The main difficulty in performing magnetic measurements in the U-2M torsatron is to take into account the contribution of the image currents arising in the metal environment under the action of plasma currents. Furthermore, the electronic equipment that registers useful signals from the magnetic sensors should have the necessary time resolution to provide discrimination, amplification and integration of the useful signals in conditions where the external magnetic field instability and the intense RF interference are observed during plasma experiments. Methods of electrical measurements by magnetic sensors are described in [6, 7].

Fig. 2 correspondingly, show the metallic environment effect on signals detected by diamagnetic loops and Mirnov coils inside and outside of the U-2M vacuum chamber simulator.

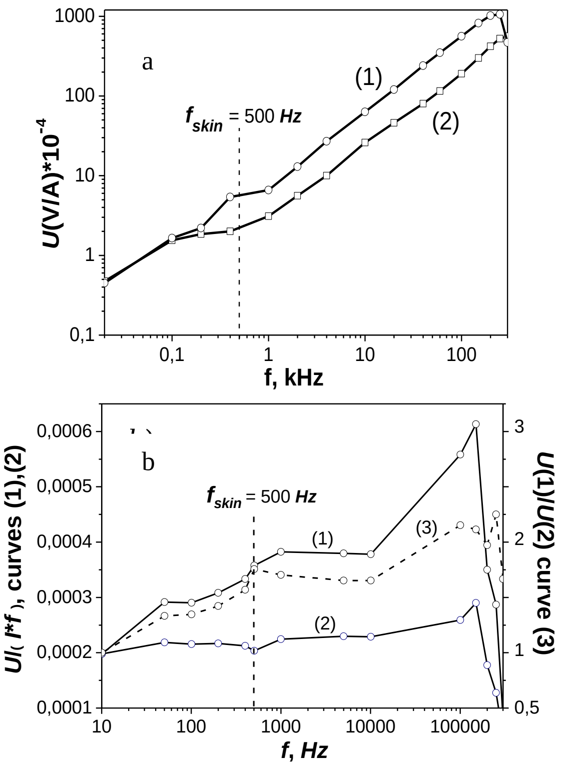
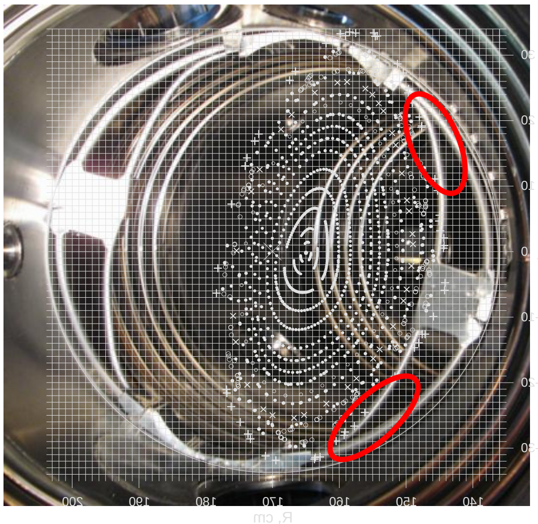


Fig. 2. U signal recorded by diamagnetic loops as a function of the frequency of current simulating poloidal plasma currents in the U-2M chamber simulator, (1) – signal from the first diamagnetic loop covering a large area, (2) – signal from the second diamagnetic loop covering a smaller area (a).
Frequency dependence of the ratio of the U signal amplitude recorded by the magnetic sensors to the current frequency and to the current value of the m =1 plasma current-simulating coil in the U-2M chamber simulator (b). Coil arrangements: (1) – inside the metal chamber and (2) – outside the metal chamber. The dashed line (3) shows the U(1)/U(2) ratio of magnetic sensor signals in and out of the chamber model

The Figure shows that at frequencies above the skin frequency $f_{skin} = \frac{c^2}{8\pi\sigma\Delta\alpha}$ for this thickness of the metallic wall of the simulator of the vacuum chamber Δ (c – light speed; s – conductivity of the metal; D – wall thickness; a – radius of the chamber), the image currents flowing in the chamber begin to influence the signals detected by magnetic sensors. While processing the measurement results of magnetic sensors in frequency ranges up to the skin frequency, the influence of the metallic environment can be neglected. At frequencies above the skin frequency, corrections should be made depending on the frequency of the detected signal.

Another problem during magnetic measurements at U-2M is thermal heating of structure elements of thermal shield of magnetic sensors that contact with edge closed surfaces. As a result, electrical insulation of conductors of diamagnetic sensors was damaged during previous experiment at U-2M torsatron. Location of two areas where destruction of electrical insulation of conductors was observed against magnetic surfaces inside the vacuum chamber of U-2M is shown by red lines in Fig. 3 above.

K_φ=0.31, φ=135° + 5.62°



K_φ=0.31, φ=270° - 5.62

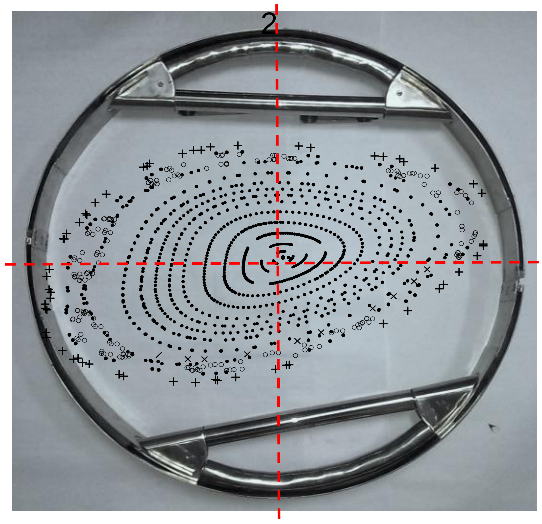


Fig. 3. The location of the thermal protection of two diamagnetic loops inside the vacuum chamber U- 2M at the beginning of the experimental company 2014 (shown above) and its new position (shown below) with respect to the magnetic surfaces in the U-2M torsatron

The reason for this overheating could be the displacement of the plasma confinement area in the horizontal direction during plasma experiments. Similar situation was also observed for another system of magnetic sensors based on the set of Mirnov coils. Since they were arranged in a similar way against magnetic surfaces in U-2M. Therefore, an upgraded thermal shield for magnetic sensors was developed and fabricated. New position of the upgraded thermal shield of diamagnetic loops against magnetic surfaces in another toroidal section is shown in Fig. 3 below. Selection of this toroidal section allows to avoid thermal overheating of the most vulnerable areas of thermal shield that are above the surface of the vacuum chamber. In this section, horizontal displacement of the plasma confinement area will not result in thermal overheating of electrical insulation of conductors of magnetic sensors. Similar arrangement against magnetic surfaces in U-2M was selected for the Mirnov coils and Rogowski loop.

CONCLUSIONS

The optimal location of magnetic sensors was determined against magnetic surfaces in torsatron U-2M. The new design of the upgraded thermal shield of magnetic sensors and their efficient arrangement in U-2M will allow to avoid destruction of electrical insulation of conductors of magnetic sensors during plasma experiments. It was demonstrated that it is necessary to take into account the influence of the metallic environment on the readings of the magnetic sensors at frequencies above the skin frequency for a given wall thickness of the vacuum chamber of U-2M.

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ОСОБЕННОСТИ ПРИМЕНЕНИЯ МОДЕРНИЗИРОВАННОЙ МАГНИТНОЙ ДИАГНОСТИКИ В ТОРСАТРОНЕ У-2М

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Для магнитных измерений на установке торсатрон Ураган У-2М разработаны модернизированные системы магнитных датчиков и регистрирующей аппаратуры. Изучены влияния металлического окружения, радиочастотных помех и нестабильности внешнего магнитного поля в торсатроне Ураган У-2М на показания магнитных датчиков во время плазменных экспериментов.

ОСОБЛИВОСТІ ЗАСТОСУВАННЯ МОДЕРНІЗОВАНОЇ МАГНІТНОЇ ДІАГНОСТИКИ В ТОРСАТРОНІ У-2М

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Для магнітних вимірів на установці торсатрон Ураган У-2М розроблені модернізовані системи магнітних датчиків і реєструючого устаткування. Вивчено впливи металевого оточення, радіочастотних перешкод і нестабільності зовнішнього магнітного поля в торсатроні Ураган У-2М на показання магнітних датчиків під час плазмових експериментів.