

# MAGNETIC DIAGNOSTICS FOR TORSATRON U-2M

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The features of application of magnetic diagnostics in torsatron U-2M are described. The methods to account for the influence of the metal environment and induced magnetic fields on the results of magnetic measurements are presented. During the experimental program on torsatron U-2M with help of magnetic diagnostics, the most important characteristics of the plasma, such as the value of the plasma energy content, the energy confinement time, the power inputted in the plasma, the value of Pfirsch-Schluter currents, the presence of magnetic islands, the shift of magnetic surfaces, the structure of MHD instabilities will be determined.

PACS: 52.55.Dy, 52.55.Hc

## 1. INTRODUCTION

Magnetic diagnostics is a set of magnetic sensors and electronic devices, which allow to determine some of the most important characteristics of the plasma as a result of registration and processing of magnitudes of the magnetic fields generated by plasma currents outside the volume confinement [1-3]. The possibilities of magnetic diagnostics in stellarator systems significantly enhanced with respect to tokomaks because of existence of a stellarator vacuum magnetic configuration. As was shown in [4], magnetic diagnostics allow to determine the value of the longitudinal plasma current, the value of the plasma energy content, the power inputted in the plasma, the energy confinement time of the plasma, shift and deformation of magnetic surfaces, the structure of magnetic islands, the structure of MHD instabilities, etc. However, to obtain such information and to measure variation of magnetic fields, a large number of magnetic sensors should be placed outside of confinement value. The main difficulty in carrying out magnetic measurements is the account of the image currents arising in the metal environment under the influence of plasma currents.

In this paper we described the features of application of magnetic diagnostics in the installation of torsatron U-2M, as well as the methods to account for the influence of the metal environment on the results of magnetic measurements.

## 2. MAIN RESULTS

Vacuum chamber of torsatron U-2M consists of a set of thin-walled sections (with wall thickness up to 5 mm) interconnected by a silphons (with wall thickness of about 1 mm). The vacuum chamber is placed in a toroidal metal case (with wall thickness up to 8 mm), on which the helical coils are mounted. Estimates show that over such metallic environment the magnetic field can penetrate without distortions, if duration of impulse front of magnetic field greater than 10 ms. Because the duration of heating on torsatron U-2M is about 100 ms, placing magnetic sensors outside the vacuum chamber will not allow us to obtain information about magnetic fields of plasma currents. Therefore, all the sensors of magnetic diagnostics must be installed inside a vacuum chamber.

However, in most modes of operation of torsatron U-2M the last closed magnetic surface can touch with the wall of the vacuum chamber. Therefore is planned to install limiters inside the vacuum chamber of torsatron U-2M. These limiters will restrict the plasma at the distance of 2 cm from the chamber walls. This distance allows installing magnetic sensors inside the vacuum chamber.

To carry out the program of research on torsatron U-2M, magnetic sensors will be installed in advance in the chamber. These sensors will register variations in the toroidal magnetic flux, as well as variations in harmonics of poloidal magnetic field over toroidal angle in the range of frequencies from 10 Hz up to 200 kHz. The value of the plasma energy content, the plasma energy confinement time and the power inputted in the plasma will be determine by registration of variations of toroidal magnetic flux and zero harmonic of poloidal magnetic field created by longitudinal plasma current. The value of Pfirsch-Schluter currents, the shift of magnetic surfaces, the structure of MHD instabilities, corresponding to the first harmonic will be determine by registration of variations of first and zero harmonics of the poloidal magnetic field. The presence of magnetic islands, shift of magnetic surfaces, the structure of the MHD instability, corresponding to the second harmonic will be determined by registration of variations of the second harmonic of the poloidal magnetic field.

To register variations of the toroidal magnetic flux we are planning to install diamagnetic loops inside the vacuum chamber. To register variations of zero, first and second harmonics of the poloidal magnetic flux over the toroidal angle, the sets of 16 mirnov coils will be installed in five sections of the torus.

Two diamagnetic loops covering different areas and located in one section of the torus will be used to compensate induced magnetic fields during the diamagnetic measurements. With the help of an analog-digital methods a useful signal, which is the same for each loop, will be extracted. Block diagram of diamagnetic measurements is shown in Fig. 1. A similar method of the diamagnetic flux measurement has been used successfully in torsatron U-3M. Before measuring the electronic circuit of an analog-digital converter is tuned so that in the absence of useful signal the resulting signal registered by diamagnetic loops was zero. Due to this, it becomes

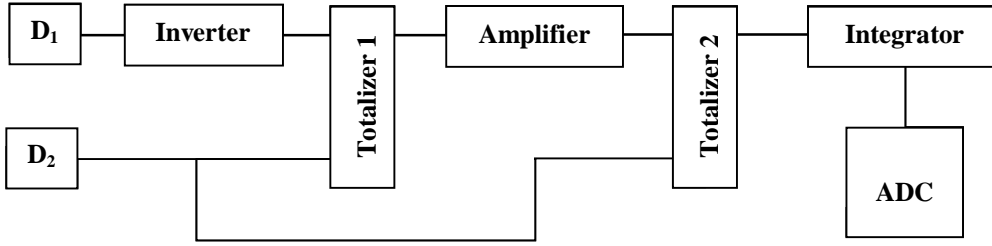


Fig. 1. Block diagram of diamagnetic measurements.  $D_1$  – diamagnetic loop I,  $D_2$  – diamagnetic loop II, ADC – analog-digital converter

possible to exclude the influence of magnetic fields created by image currents in the metal environment. To measure variations in the poloidal magnetic field components, the magnetic sensors installed in five sections of the torus will be used. Provided that, when  $N/R \ll m/b$  ( $R$  – a large radius,  $r$  – a small radius,  $N$  – number of periods of magnetic field over the toroidal angle and  $m$  – number of periods of magnetic field over small azimuthal angle,  $b$  – radius of the surface on which is carried out magnetic measurements), the measurements of variations in the poloidal magnetic field component give objective information about the structure of the longitudinal plasma current.

16 magnetic sensors will be placed in each of the five cross-section of the torus. The real ratio is  $b/a \approx 1.5$ . This ratio will allow to extract poloidal harmonics with  $m = 0$ ,  $m = 1$  and  $m = 2$  from a common signal of the magnetic sensors. With the help of magnetic measurements which will be carried out in the five sections of the torus it will be possible to measure the perturbations with  $N = 0$  and  $N = 1$ . Placing of magnetic sensors in special selected sections of the torus will allow us to extract perturbations with  $N = 4$ . As a result, it will be possible to monitor the behavior of the fundamental harmonic of torsatron magnetic field with  $m = 2$  and  $N = 4$ .

In total, with the help of sets of 80 magnetic sensors installed in five sections of the torus it can be measured following quasi-stationary and variable harmonics of plasma currents:

- 1) with  $m=0$ ,  $N=0$  – longitudinal plasma current;
- 2) with  $m=1$ ,  $N=0$  – horizontal displacement of the plasma current, magnetic field of Pfirsch-Schluter currents, the vertical displacement of the plasma current and the time variation of the radial electric field [6];
- 3) with  $m=2$ ,  $N=1$  – island structure of magnetic surfaces under  $\nu/2\pi=0.5$  ( $\nu$  – the rotational transform angle);
- 4) with  $m=1$ ,  $m=2$ ,  $N=4$  – helical equilibrium plasma currents.

The above mentioned magnetic sensors can register variation in the magnetic fields at frequencies from 10 Hz up to 200 kHz. Therefore it is possible to register MHD fluctuations of corresponding structure with  $m=0$ ,  $m=1$ ,  $m=2$  and with  $N = 0$ ,  $N=1$ ,  $N=2$ ,  $N=4$ .

It should be noted, that for measuring variations of the poloidal magnetic field component with  $m \neq 0$  it is necessary to take into account the influence of image currents that flow in the metallic environment. During the measurements of poloidal magnetic fields, the image currents will be taken into account by using numerical methods for processing recorded signal on the basis of special model measurements in a vacuum chamber of

torsatron U-2M. For example, Fig. 2 shows dependence of the ratio of the signal detected by magnetic sensors to the frequency and the value of current of the coil simulating the plasma current with  $m = 1$ .

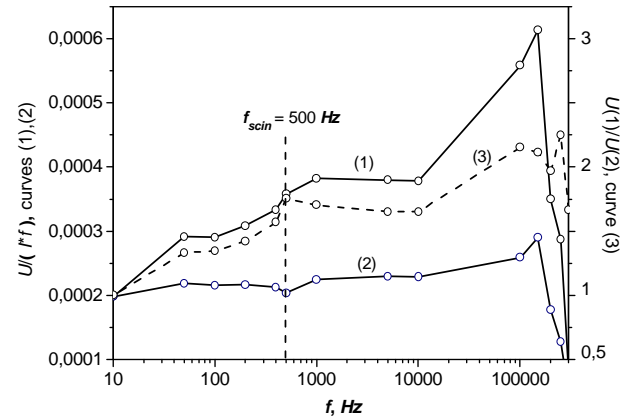


Fig. 2. The dependence of ratio of the signal amplitude  $U$  recorded by magnetic sensors to the frequency and the value of current of the coil simulating the plasma current with  $m = 1$ . Location of coils: (1) – inside the metal chamber and (2) – out of the metal chamber. The dotted line (3) shows the ratio  $U(1)/U(2)$  recorded signals of the magnetic sensors inside and outside the simulator of the vacuum chamber

The measurements were performed inside and outside the simulator of the stainless steel vacuum chamber, which is similar to a chamber of torsatron U-2M ( $b/r_0 \approx 0.9$ ,  $r_0$  – radius of the metal chamber). The figure shows that at frequencies above the skin frequency

$$f \gg f_{skin} = \frac{c^2}{8\pi\sigma\Delta a} = 500 \text{ Hz}$$

for given configuration and thickness of the wall of the simulator of the vacuum chamber, the recorded signal is almost 2 times higher than one outside the simulator ( $c$  – light speed,  $\sigma$  – conductivity of the metal,  $\Delta$  – wall thickness,  $a$  – radius of the chamber). This is due to the fact that the image currents flow in the metal chamber, and the magnetic field of the plasma current does not penetrate through the metallic environment. At frequencies below the skin frequency, the magnetic field of the plasma current penetrates through the metal wall of the simulator of the chamber and the recorded signal with decreasing frequency is the same inside and outside the chamber. At frequencies above 100 kHz, resonance effects appear related to the presence of

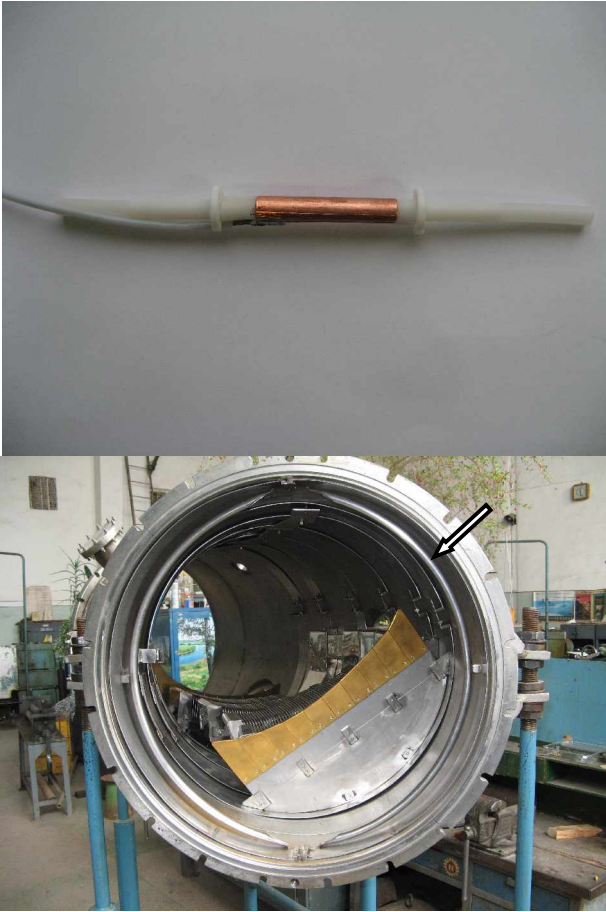


Fig. 3. Photos of the module with a magnetic sensor (top) and location of constructional elements of magnetic sensors inside the simulator of the vacuum chamber of torsatron U-2M (photo below, in the foreground marked by the arrow, RF antenna is visible in the background)

reactivity introduced by the metal environment in measuring contour of the magnetic sensors. Calculations showed that the influence of the metal environment on the second and higher azimuthal harmonics of poloidal magnetic field, is similar to that of the first azimuthal harmonic.

Pictures of modules with a magnetic sensor measuring the poloidal magnetic field components, as well as location of constructional elements of the magnetic sensors inside the simulator of the vacuum chamber of torsatron U-2M are shown in Fig. 3. Due to the modular design of elements of magnetic diagnostics, they can be installed inside the vacuum chamber of torsatron U-2M through vacuum ports, without disassembling the chamber.

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Article received 14.10.10

## МАГНИТНАЯ ДИАГНОСТИКА ДЛЯ ТОРСАТРОНА У-2М

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Описаны особенности применения магнитной диагностики в торсатроне U-2M. Представлены методы учета влияния металлического окружения на результаты магнитных измерений. В ходе экспериментальной программы на торсатроне U-2M с помощью магнитной диагностики будут определяться наиболее важные характеристики плазмы, такие, как величина энергосодержания плазмы, энергетическое время жизни, введенная в плазму мощность, величина токов Пфирша-Шлюттера, наличие магнитных островов, смещение магнитных поверхностей, структура МГД- неустойчивостей.

## МАГНІТНА ДІАГНОСТИКА ДЛЯ ТОРСАТРОНА У-2М

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Описано особливості застосування магнітної діагностики в торсатроні U-2M. Представлено методи врахування впливу металевого оточення на результати магнітних вимірювань. У ході експериментальної програми на торсатроні U-2M за допомогою магнітної діагностики визначатимуться найбільш важливі характеристики плазми, такі, як величина енерговмісту плазми, енергетичний час життя, введена в плазму потужність, величина струмів Пфірша-Шлюттера, наявність магнітних островів, зсув магнітних поверхонь, структура МГД- нестійкостей.