MICROWAVE DIAGNOSTIC SYSTEM OF THE URAGAN-2M TORSATRON

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The construction of microwave sections together with results of loss calculation in the microwave lines for different frequencies are presented. The construction of microwave lead-ins is also described. The whole system has been well-tested on the Uragan-2M torsatron in conditions of SHF and RF cleaning at a low magnetic field, and of pulse regime with a higher magnetic field up to 6 kOe. The results of testing are illustrated by temporal evolutions of plasma density and by digitalized signals from the detector.
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INTRODUCTION

The microwave interferometry and reflectometry systems are created and tested to study time and space characteristics of plasma density in the renewed U-2M torsatron [1]. Cleaning of internal surfaces of the chamber is made by low density SHF and RF discharges. Therefore, the diagnostic system is developed for plasma probing on frequencies f=10–140 GHz with measurements of phase shifts $\Delta\varphi = (0.1-40)\pi$. To determine density profile at a low density, n~10^{12} cm^{-3}, application of reflectometry on frequencies $f\leq$ 10 GHz is inexpedient. Therefore, it is necessary to carry out interferometry along several chords.

In an l=2 torsatron the cross-section of the plasma formation bounded by a magnetic surface looks as an extended oval. Therefore, it is necessary to probe the plasma along the major and minor axes.

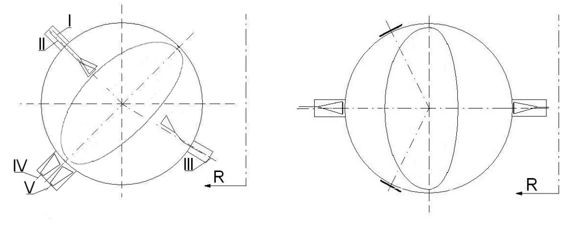
Indication of phase shifts is made by phase beats and raster methods.

The relationship between phase shift and density is given by the formula $\Delta\varphi = -\pi C_l \dfrac{l}{\lambda}\dfrac{\bar{n}}{n_{cr}}$, where $\bar{n}$ - is the electron density averaged over the length of wave propagation. The factor C_l is determined by density distribution. At $\bar{n} < 0.2\ n_{cr}$ C_l practically does not depend on the form of this distribution ($C_l\approx$1) and the phase shift of the wave is directly connected with the average density of electrons.

The indication of phase shift by the raster method is distinct by the displacement of characteristic points of phase beats determined by the way of programming, rather than by an instrumental way.

MEASUREMENT TECHNIQUES

To probe the plasma along the major and minor axes of the oval, 5 waveguide channels in the poloidal cross-section of the torus between the 9-th and 10-th toroidal field coils and 2 waveguide channels between the 12-th and 13-th coils are installed. The horn antennas allow to make probing by the ordinary wave along and across the the oval of plasma formation in two various cross-sections (Fig.1a,b). The antennas II and III are intended for interferometry and the antenna I is for reflectometry. The antennas are designed as collapsible ones and are attached to the waveguides inside the chamber (Fig.2). However, in the regime of UHF cleaning the confining magnetic configuration is not formed and only the antennas placed outside the chamber are used.



a *b*

Fig.1. Antenna arrays in the cross-sections (a) between 9-th and 10-th coils; (b) between 12-th and 13-th coils

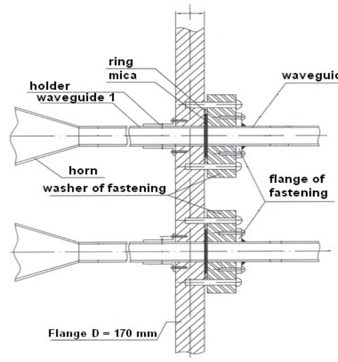


Fig.2. Construction of microwave antenna insertion into the chamber

The cross-sections of antenna I and antenna II waveguides are 11×5.5 mm and 7.2×3.4mm, respectively. That of antenna III is 7.2×3.4 mm and those of antennas IV and V are 17×8.5 mm. The sizes of waveguide channels provide probing within the 10-140 GHz range of frequencies. The lengths of waveguide lines amount 15-18 m. Experimentally measured and calculated [3] signal attenuations in the waveguides are tabulated in the Table. The losses in connections and due to mode conversion are not considered here.

Calculated and experimental values of signal attenuation in the waveguide lines

Waveguide size	17×8.5 mm, λ = 1.2 cm		11×5.5 mm, λ = 1.0 cm		7.2×3.4 mm, λ = 0.83 cm	
Type of oscil.	Calc. *dB*/m	Exper. *dB*/m	Calc. *dB*/m	Exper. *dB*/m	Calc. *dB*/m	Exper. *dB*/m
TE_{10}	0.24	0.7	0.42	1.1	0.44	0.78
TE_{20}	0.32	-	0.91	-	-	-
TE_{11}	0.77	-	-	-	-	-

In Fig.1b the arrangement of waveguides in the poloidal cross-section between the 12-th and 13-th toroidal coils is shown. In this case, the antennas are outside of the chamber and the probing is made through a quartz glass. The waveguide cross-section is 11×5.5 mm. In the Table the values of signal attenuation for waveguides in this section are presented too. Such an arrangement of waveguides allows to get rid of electrical interference that can be picked up by waveguide elements in the vacuum chamber. In this case, the probing is made only along the minor radius of the plasma formation.

The applied sources of microwave radiation allow to make probing within the range of 9-54 GHz, ensuring measurements of the average density 5.0×10^{10}– 1.2×10^{10} cm^{-3} and the local density 6.0×10^{10}– 3.6×10^{13} cm^{-3} (by wave reflection).

The sources of microwave radiation and the receiving equipment are enclosed into a steel box. From here, the signals are transmitted to the control hall by fibre-optic lines. To avoid electric interference, the receiving equipment is electrically isolated from the waveguide lines by insertion of dielectric waveguides between the metal waveguides.

In this work, besides determination of phase shift by interferogram extremums, a "zebra" type method is also used with application of a program code for reproduction of interference strips and their dynamics with density variation [3]. The aim of program code is in finding maximum points of the set array and to display them on the modulating saw. The maximum is searched on a segment with *N* points. The point with the maximal value should be in the middle of the segment, otherwise, the segment is one point displaced and the process is repeated (Fig.3).

EXPERIMENTAL RESULTS

Fragments of signals without and with the plasma together with the modulating sawtooth-like pulse are presented in Fig.3. The sawtooth period is 0.5 ms. The signals are detected during RF cleaning (Fig.3). Also, the detection could be possible in the pulse regime with a higher magnetic field attaining 6 kOe. The phase beats are displaced in time when the plasma occurs in the chamber.

Using the "zebra" type method of phase shift indication, the interference strips are received with the use of program code (Fig.4). Here, fragments of strips are presented during occurrence of plasma in the chamber. The distance between strips is 2π . Some points drop out of the general picture during RF cleaning and in the pulse regime, this being connected with density fluctuations within the frequency modulation period. Using Fig.4, we can construct density evolution in time (Fig.5).

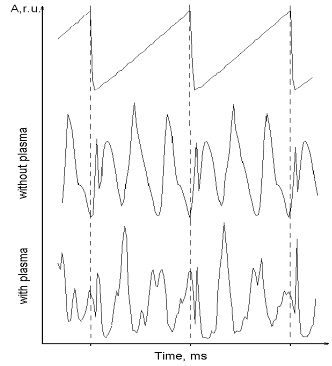


Fig.3. Signals from detector in RF cleaning regime, λ =0.8 cm

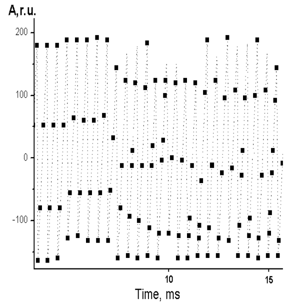


Fig.4. Strips in RF cleaning regime λ =0.8cm

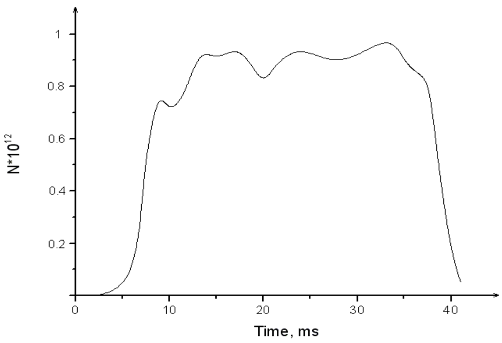


Fig.5. Time distribution of plasma density in the RF cleaning regime

Experiments on density determination by the interferometry method have been carried out. An example of signal from the detector is presented in Fig.6. In the case 1, the probing is made along the central chord (minor axis) of plasma formation at the wavelength λ=8.2 mm (L=30 cm), while in the case 2, along some outward-shifted chord (major axis) at the wavelength λ=12 mm (L=120 cm). A corresponding time evolution of density is shown in Fig.7.

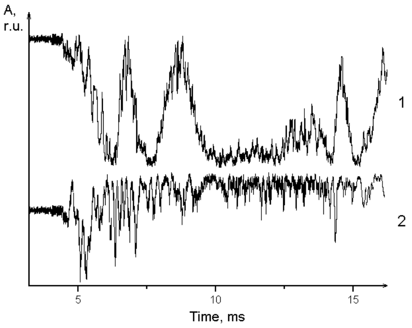


Fig.6. Interferometer signals with plasma probing along the central (1) and outward-shifted (2) chords

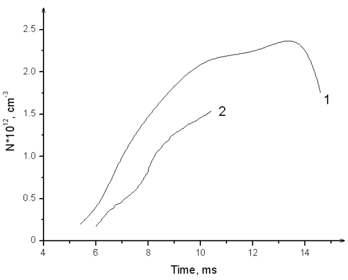


Fig.7. Time behavior of plasma density, H=4.8 kOe

CONCLUSIONS

The results of first experiments on the renewed U-2M torsatron obtained with the help of a microwave diagnostic system show a possibility of density measurements in a wide range $n = 10^{10} - 5\times10^{12}$ cm^{-3}.

The raster method of phase shift indication based on program determination of interference strip shifting with plasma density variation has been developed and applied.

It is necessary to adapt the system for transmission and indication of signals with frequencies up to 140 GHz when the density increases up to the planned values $5\times 10^{13} - 10^{14}$ cm^{-3}.

It is intended to develop multi-chord probing up to 5 channels for the best spatial resolution.

In these experiments the maximum density up to $\overline{n} = 5\times10^{12}$ cm^{-3} along the minor axis and approximately 30% smaller one along the major axes are observed, this difference might indicate that the maximum of density is not crossed by the probing beam.

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СВЧ- ИЗМЕРИТЕЛЬНЫЙ КОМПЛЕКС НА ТОРСАТРОНЕ УРАГАН-2М

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Представлены конструкции СВЧ-трактов с расчетом потерь в линиях на различных частотах и конструкции СВЧ-вводов. Описанный СВЧ-комплекс испытан на торсатроне Ураган-2М в режимах СВЧ- и ВЧ- чистки при низкой напряженности магнитного поля, а также в импульсном режиме с магнитным полем до 6 кЭ. Результаты измерений иллюстрируются временными зависимостями плотности и цифровыми сигналами, полученными с детектора.

НІЧ- ВИМІРЮВАЛЬНИЙ КОМПЛЕКС НА ТОРСАТРОНІ УРАГАН-2М

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Представлено конструкції НВЧ-трактів з розрахунком втрат в лініях на різних частотах і конструкції НВЧ-введень. НВЧ-комплекс, що описано, був випробуваний на торсатроні Ураган-2М в режимах НВЧ- і ВЧ-чищення при низькій напруженості магнітного поля, а також в імпульсному режимі з магнітним полем до 6 кЕ. Результати вимірювань ілюструються часовими залежностями густини і цифровими сигналами, отриманими з детектора.