FIRST TESTS OF THE BIASED MOVABLE B_4C-LIMITER IN THE URAGAN-2M TORSATRON UNDER RF AND UHF WALL CONDITIONING

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The work describes the design of a multifunctional B_4C-limiter, and reports preliminary results from experimental study of the limiter operated at steady-state and pulsed RF discharge cleaning regimes in the Uragan-2M torsatron.
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1. INTRODUCTION

The problem of improving vacuum-plasma conditions in the Uragan-2M torsatron (U-2M) is now considered as the most important. This is caused by the design features of the magnetic trap, namely, a low pumping speed of the vacuum system, the absence of a divertor, the possibility of direct plasma-wall interactions, etc. In tokamaks [1], the limiters are used to suppress plasma wall interactions and in that way to reduce the amount of heavy impurities in the plasma. Some data on the use of limiters in stellarators can be found in the literature [2]. However, it is not quite clear if the way proposed there would be useful in the case of U-2M, in view of the fact that only the RF method is used for plasma creation and heating, that does not exclude the possibility of plasma generation beyond the region of existence of closed magnetic surfaces. Therefore, it was of interest to pepare a limiter in the U-2M and to clarify its influence on vacuum-plasma conditions by using different limiter head plate positions relative to the plasma core boundary, and also, various plate materials and configurations. Besides the main goal, the limiter might be also used in experiments to investigate head plate material erosion and transport behavior, the possibility of partial solid target boronization of vacuum chamber walls, to perform electrode bias experiments, etc. At the initial stage of experiments, a hot-pressed boron carbide was selected as a material for the limiter head plate, because it has been previously investigated in detail [3] and was used in the U-3M torsatron limiter experiments [4].

2. EXPERIMENTAL AND RESULTS

To perform the experiments, a movable limiter was designed, manufactured and installed in the U-2M vacuum chamber. The limiter consists of the head plate (90x90x10 mm) fabricated from a boron carbide plate hot-pressed in vacuum [3], a plate-drive assembly, and two Langmuir probes. One of the probes was located behind the limiter plate at a distance of 3 cm, and was intended for plasma stream measurements on the back side of the limiter plate. The limiter head plate is placed on an insulator. This allowed us to measure signals from the limiter plate (current, potential) and to switch on/off negative or positive bias (pulsed or stationary) with amplitudes up to 250…400 V. After checking for tightness, the limiter was installed in the U-2M for tests under edge plasma conditions (Fig.1). The schematic sketch of the experiment is given in Fig.2.

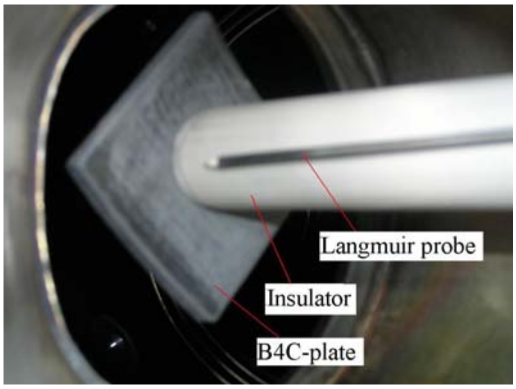

Fig.1. The movable B_4C-limiter in the branch pipe of port #1 of the Uragan-2M torsatron

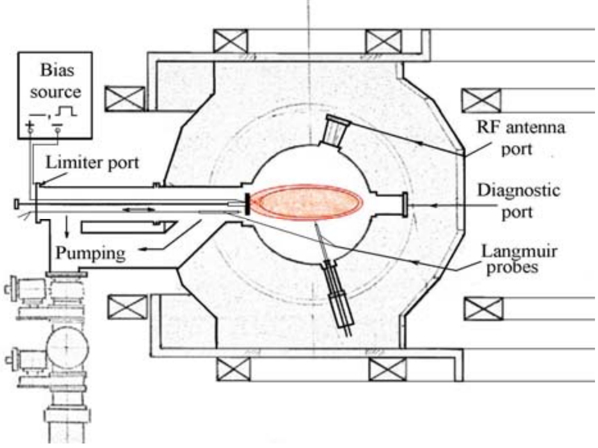

Fig.2. Schematic drawing of the experiment with B_4C-limiter in the U-2M torsatron

It is seen that at the present configuration the limiter is open, pumped, biased and movable. The tests were carried out in the stationary plasma discharge cleaning regime with typical of U-2M parameters: hydrogen pressure was 10^{-2} Pa, electron density $\sim 2\times10^{12}$ cm^{-3}, electron temperature ~10…15 eV, magnetic field ~0.075 T, the RF generator power ~1 kW at a frequency of 8.3 MHz, the UHF generator power ~2 kW at a frequency of 2.375 GHz (electron-cyclotron resonance conditions). During the tests, the limiter plate was moved from the chamber wall to the axis for a distance of up to 10 cm. With that, the signals from the Langmuir probes and the H_α line intensity were measured. The signals from the limiter were also registered (Fig. 3). It can be seen from Fig. 3 that in the RF plasma case, the signal polarity changes from positive to negative at a distance of 4…5 cm from the chamber wall, and the signal intensity increases essentially. Note, that in this region the last closed magnetic surface is located according to U-2M magnetic configuration measurements ($K_\varphi = 0.32$) [5].

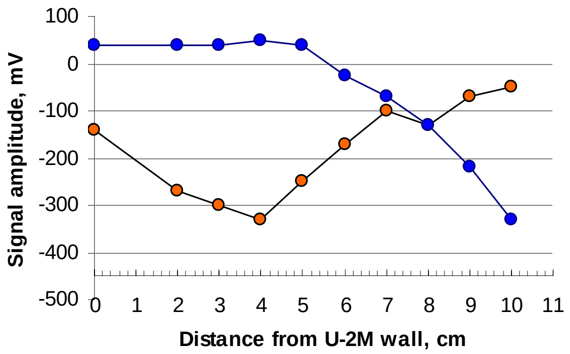

Fig.3. Limiter signal amplitude versus distance from the U-2M wall during limiter motion to the plasma axis:
● – steady-state wall conditioning by RF plasma,
●- steady-state wall conditioning by UHF plasma

Langmuir probe experiments have shown that the edge plasma characteristics are practically independent of the limiter plate position for both RF and UHF discharges (current-voltage characteristics are shown in Fig. 4). The signals from the probe placed at the plasma column boundary showed no changes during limiter moving to the plasma axis. At the same time, the signals from the probe placed behind the plate had constant low amplitudes for all limiter positions. Spectroscopic measurements also showed no essential influence of the limiter plate repositioning in the plasma on the H_α line intensity.

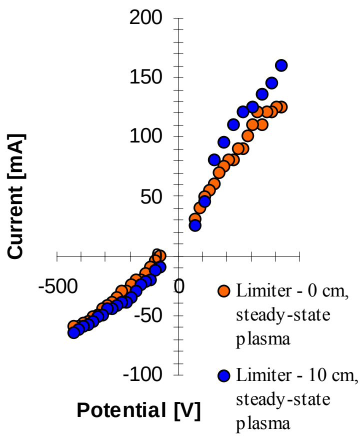

Fig.4. Limiter current-voltage characteristics measured under steady-state RF plasma discharge cleaning conditions

The second kind of limiter test experiments was carried out under RF plasma pulsed-discharge cleaning conditions. The typical parameters were: hydrogen pressure $p = 10^{-3}$ Pa, electron density ~ 5×10^{11} cm^{-3}, pulse duration 20 ms, magnetic field ~ 0.47 T, the RF generator power ~ 80 kW at a frequency of 5.6 MHz. The current-voltage characteristics measured at two different limiter positions, when the head plate was located flush-mounted with the vacuum chamber wall and when it was at a 10 cm distance from the wall, are shown in Fig. 5. A rather high level of data scattering in the case of pulsed discharge regime is caused by unstable operation of RF generator.

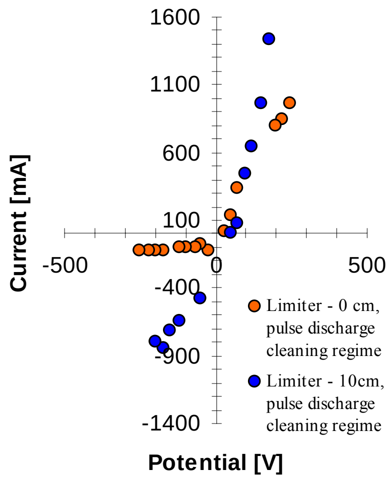

Fig.5. Limiter current-voltage characteristics measured under pulsed RF discharge cleaning conditions

3. DISCUSSION

The absence of the limiter head plate position effect (~10 cm from the wall) on the signals of Langmuir probe located in the plasma column cross-section different from that of the limiter means that at least with the present limiter head plate configuration its inputting through the plasma boundary does not lead to the cutoff of the plasma column (except the zone behind the head plate). Perhaps, this is due to the fact that in contrast to other plasma machines with limiters [1, 2], only the RF method is applied to create and to heat plasma in the U-2M. However, to confirm this assumption, additional experiments with other limiter head plate configurations in real working regimes are required.

It is obvious from Fig. 5 that ion currents up to 1 A might be extracted even from not powerful RF plasma pulses. These values are comparable with those provided by the pulsed discharge cleaning regime in the U-3M torsatron (about 200 mA at (-90) V [3], which was realized with the following typical parameters: $p = 10^{-2}$ Pa, $n_e = 2\times10^{12}$ cm^{-3}, $T_e = 10…15$ eV, B = 0.035 T. The plasma pulse duration was 50 ms, the generator power 80 kW and the generator frequency was 5.4 MHz. But unlike the U-3M limiter experiment, in the present case we have no so-called arc regime, when the ion current value increases up to 10 A ([3], Fig. 6). The reasons for this difference in the ion current behavior are not quite clear. One of them could be a high level of plate surface finish. The other reason may lie in plasma power insufficiency for arcing.

If the B_4C erosion coefficient is put to be ~10^{-2} at/ion [6] and the negative pulsed bias duration 20 ms, then the number of sputtered particles would make up about 10^{16} per pulse. It requires about 2.5×10^{20} boron particles (~10^4 pulses) to form a monolayer coating on the whole surface of the U-2M vacuum chamber walls.

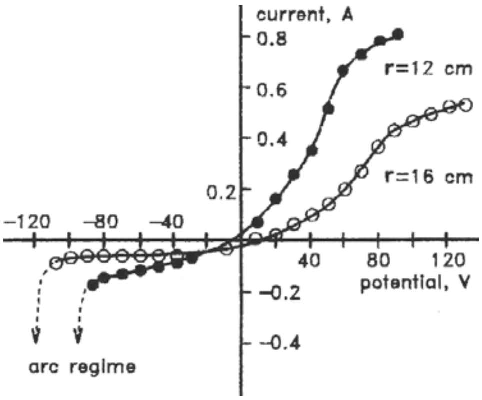

Fig.6. Current-voltage characteristics of B_4C limiter in the Uragan-3M torsatron [4] (pulsed discharge cleaning regime)

So, a few days of pulsed discharge cleaning regime might be enough to produce a few monolayer boron carbide coatings for U-2M partial boronization.

4. CONCLUSIONS

A movable B_4C-limiter has been designed, manufactured and installed in the Uragan-2M torsatron. The first experiments at RF wall conditioning regimes have shown no cutoff of the plasma column (excepting the zone behind the limiter plate) after crossing the last closed magnetic surface with the limiter plate and its moving to the plasma column axis.

Essential ion currents might be extracted during the RF plasma pulsed-discharge cleaning regime and supplied to the head B_4C-plate; that could be used for partial solid-target boronization in the Uragan-2M torsatron.

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ПЕРВЫЕ ИСПЫТАНИЯ ПОДВИЖНОГО B_4C-ЛИМИТЕРА В УСЛОВИЯХ ВЧ- И СВЧ-ЧИСТКИ ТОРСАТРОНА УРАГАН-2М

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Представлены конструкция и предварительные результаты экспериментального исследования использования B_4C-лимитера во время стационарных и импульсных режимов чистки ВЧ-разрядами в торсатроне Ураган-2М.

ПЕРШІ ВИПРОБУВАННЯ РУХОМОГО B_4C-ЛИМИТЕРА В УМОВАХ ВЧ- І СВЧ-ЧИЩЕННЯ ТОРСАТРОНА УРАГАН-2М

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Представлено конструкцію і попередні результати експериментального дослідження використання B_4C-лимитера під час стаціонарних і імпульсних режимів чищення ВЧ-розрядами в торсатроні Ураган-2М.