DECREASING WATER CONCENTRATION IN THE URAGAN-3M DEVICE WITH UHF DISCHARGE

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Uragan-3M device vacuum chamber is a cylinder with volume of 70 m^3. Between the operation series, it is opened to the atmosphere for scientific and technical works. The problem of high water vapour concentration in the residual gas appears each time the chamber is closed and pumped. Effective water vapour removal can be achieved by baking the vacuum chamber walls at high temperatures (200…400°C) or increasing atomic hydrogen flow produced by the wall conditioning discharge in the plasma confining volume, as far as H_2O detachment speed should be higher than adhesion. It's not technically possible to heat Uragan-3M device vacuum chamber. Room temperature of the vacuum chamber walls is not an obstacle for an UHF discharge with high enough plasma density ($8 \cdot 10^{10}$ cm^{-3}).

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INTRODUCTION

While the most effective technique of decreasing water concentration in residual gas is baking with heating fusion device walls up to 250°C [0], sometimes effectively combined with discharge cleaning [0, 0]. Uragan-3M is conditioned only by discharges [0].

The first stage of procedure of wall conditioning at torsatron Uragan-3M (U-3M) by low temperature plasma of UHF discharge at ECR frequency allows to use low power (less than 3 kW) for effective chamber cleaning from water vapour and oxygen after closing chamber and start of vacuum pumping. After this, other impurities removal from inner torsatron vacuum chamber surfaces is provided at the second stage (RF cleaning) of wall conditioning. At the first stage, the important role is played by the neutral hydrogen atoms produced during UHF discharge wall conditioning.

DESCRIPTION OF THE EXPERIMENTAL SETUP

The UHF generator has power up to 2.5 kW at a frequency of 2.45 GHz. Output microwave power was launched using a UHF antenna of a horn type fixed at the inner wall of the torsatron chamber.

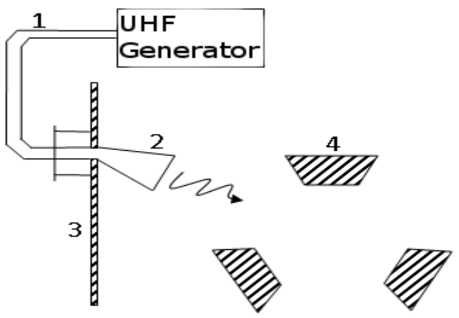

Fig. 1. Side view of microwave antenna in the chamber of U-3M. 1 – wave-guide; 2 – microwave horn-type antenna; 3 – chamber wall; 4 – the cross section of the magnetic field windings

Horn antenna was used to ensure a smooth transition of UHF radiation in space the vacuum chamber. Transmission of UHF power from the generator to the UHF antenna is made through the waveguide.

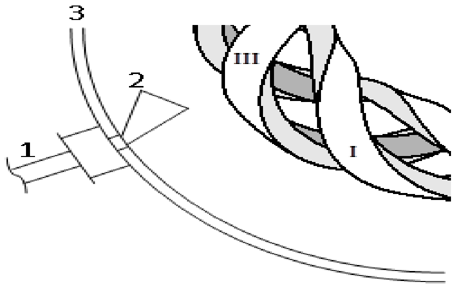

Fig. 2. Top view of microwave antenna in the chamber of U-3M. 1 – wave-guide; 2 – microwave horn type antenna; 3 – vacuum vessel wall

In Fig. 1 and Fig. 2 are schematic images of the UHF system (the wave-guide and antenna) against the magnetic windings position, and in Fig. 3 – the photo of UHF discharge seen in the gap between helical coils.

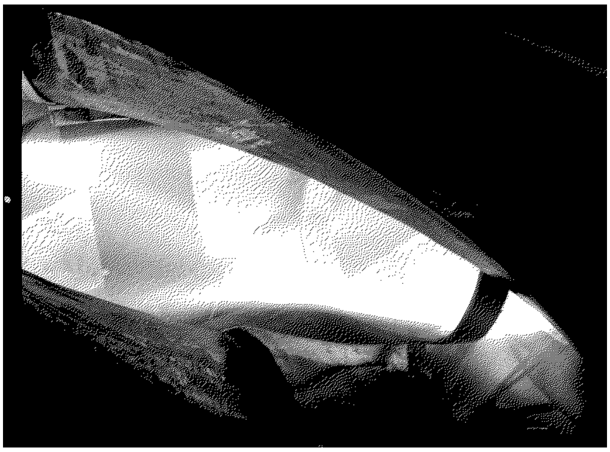

Fig. 3. Photo of luminescence of the continuous UHF discharge in U-3M

HYDROGEN CHEMICAL REACTIONS

The ionization and dissociation are the basic mechanisms of hydrogen molecules disintegration by the plasma electrons:

$e + H_2 \rightarrow 2e + H_2^+$ – ionization,

$e + H_2 \rightarrow e + H + H$ – dissociation,

$e + H_2 \rightarrow e + H_2^* \rightarrow e + 2H + h\nu$ – dissociative excitation.

The most intensive process is the second one, the generation of neutral hydrogen atoms. These atoms have Franck-Condon energies of 0.6…3 eV. They are able to desorb the water molecules absorbed by the metal surfaces by elastic impact that is equivalent to heating them up to 1000°C. Highly heated water molecules make several collisions with walls and have a chance to be pumped out.

EXPERIMENT

To implement the regime of cleaning the UHF power was supplied into the device in a continuous mode (CW–Continuous Wave). Under the operating frequency f_0~2.3 GHz, magnetic field B_0~700...1200 G and a hydrogen pressure of $p\sim5\cdot10^{-5}$ Torr, a low-temperature plasma with density $n_e\sim10^{11}$ cm^{-3} and $T_e\approx3$ eV is created.

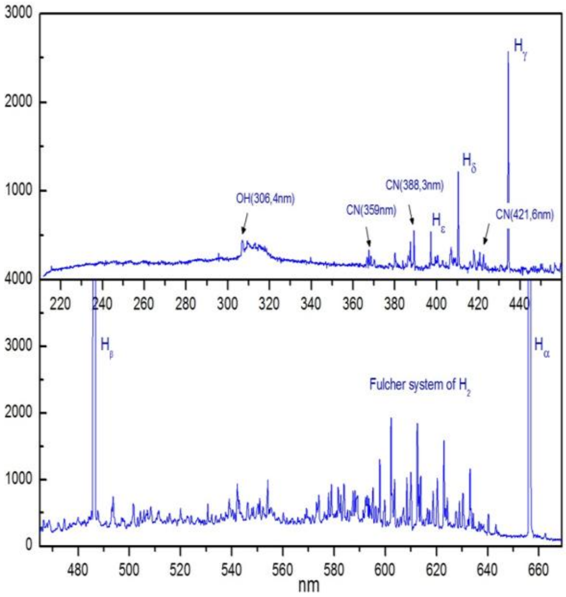

Fig. 4. The optical spectrum of the UHF discharge

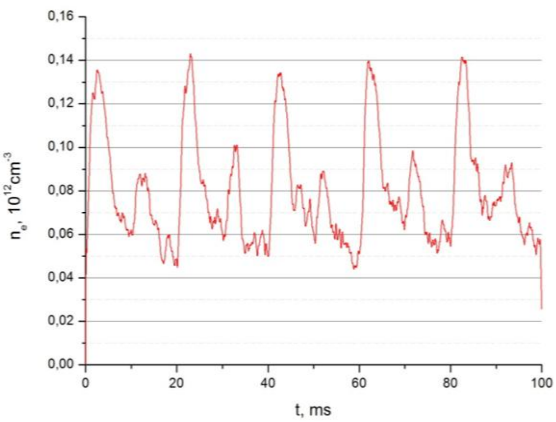

Fig. 5. Time behavior of average plasma density

The interaction of the plasma column and the inner surface of magnetic windings is controlled with magnetic field magnitude. The variation of the magnetic field strength does position the ECR layer inside the plasma column: closer or further from the inner magnetic winding surfaces. Currently it was as much close to the windings for safety of elements of plasma diagnostics placed inside vacuum chamber that can suffer from the electrons accelerated with ECR.

The analysis of the UHF discharge optical spectrum obtained with the Spectrometer SL40-2, two-channel spectrum analyzer, shows easily distinguished OH peak at 306 nm. Presence of water inside of UHF discharge is clearly seen by presence of OH emission line in optical spectrum of the UHF discharge (Fig. 4).

The average electron density during the UHF discharge, Fig. 5, was measured using the 140 GHz interferometer with a COS-SIN (I-Q) detection scheme.

Strong time variation of the plasma density seeing in Fig. 5 is due to power pulsations of the UHF generator.

RESULTS

Studies have shown that in order to achieve the acceptable results the UHF cleaning should be lasted for ~15 hours. The partial pressure of water vapor in the residual gas is halved during this time period, Fig. 6.

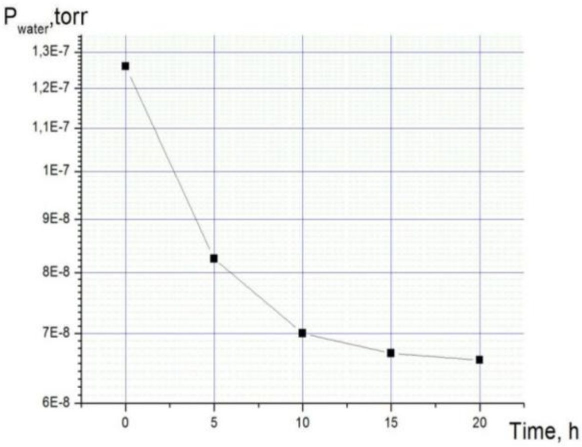

Fig. 6. The dependence of the presence of H_2O in the vacuum chamber of torsatron Uragan-3M on the duration of the UHF clean

The omegatron type partial pressure gage – IPDO-2 (mass spectrometer) – was used to monitor the pressures of gas impurities in the vacuum chamber permanently. Mass spectrometer is placed at the distance of three meters from vacuum chamber to avoid influence of the U-3M magnetic fields on measurements.

Certain impurity gases partial pressures are used to monitor vacuum chamber state during both UHF and RF cleaning (the first and the second stage of the wall conditioning accordingly):

Impurity gases

Mass	Gas	Mass	Gas
2	H_2	18	H_2O
14	N	28	$CO+N_2$
15	CH_3	40	Ar
16	CH_4+O	$\sum C_nH_m$	hydrocarbons
17	OH+NH_3		

The described regime for inner surfaces cleaning is effective only for 18th mass, which is associated with water (Fig. 7). So, as soon as sufficiently small H_2O concentration is achieved (after 12-15 hours in current experiment) during continuous UHF cleaning, the second stage, impulse RF discharge cleaning of wall conditioning, should be enabled. Impulse RF discharge cleaning deletes CO, CO_2 and hydrocarbonates from vacuum chamber more effectively.

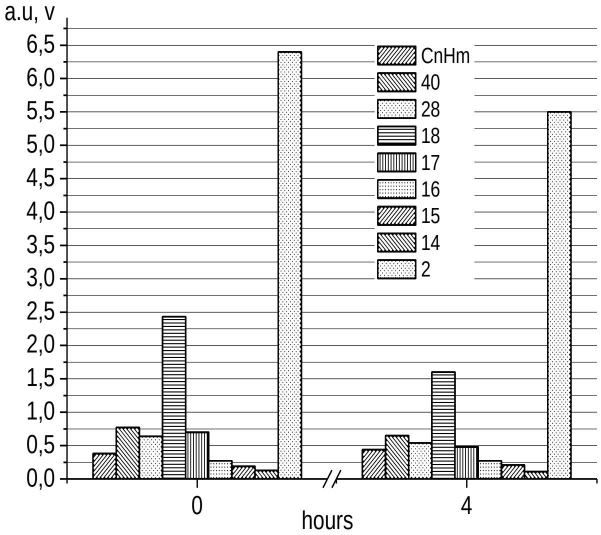

Fig. 7. Residual partial pressures of some gases in different stages of cleaning. The legend contains the mass numbers registered by a mass spectrometer

SUMMARY

By the use of UHF power a significant reduce of the concentration of water in the U-3M vacuum chamber was obtained at an initial stage of the chamber cleaning.

The UHF cleaning was found is easily implemented and cheap.

Microwave cleaning during longer than 15 hours is less efficient.

This method affects mainly the concentration of water in the vacuum chamber.

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REFERENCES

1. F. Waelbroeck, J. Winter, P. Wienhold and L. Kiinen. Effects of Wall Conditioning on Plasma Parameters, Impurities and Hydrogen Recycling in TEXTOR // *Journal of Nuclear Materials.* 1984, v. 121p. 249-253.
2. T. Arai et al. Wall Conditioning in JT-60 // *Journal of Nuclear Materials.* 1987, p. 145-147.
3. N. Noda et al. Wall Conditioning of the Jipp T-II Torus by AC Discharge Cleaning // *Journal of Nuclear Materials.* 1982, v. 111, 112, p. 498-501.
4. A.V. Lozin et al. Cleaning inner vacuum surfaces of the Uragan-3M device with HF discharges // *Plasma Physics Reports.* 2013, v. 39, № 8, p. 624-631.

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УМЕНЬШЕНИЕ КОНЦЕНТРАЦИИ ВОДЫ В УСТАНОВКЕ УРАГАН-3М СВЧ-РАЗРЯДОМ

М.М. Козуля, В.Б. Коровин, А.В. Лозин, А.Ю. Красюк, Ю.К. Миронов, Р.О. Павличенко, В.С. Романов, А.Ф. Штань, С.И. Солодовченко, Д.И. Барон, А.Н. Шаповал, В.Я. Чернышенко, В.К. Пашнев, и команда торсатрона Ураган-3М

Вакуумная камера установки Ураган-3М представляет собой цилиндр из нержавеющей стали объемом ~70 м^3. Периодически вакуумная камера вскрывается для напуска атмосферного давления с целью проведения научных и технических работ. После ее закрытия и откачки до высокого вакуума, появляется проблема, связанная с высокой концентрацией воды в остаточном газе. Для эффективного удаления паров воды обычно используется прогрев стенок камеры при температуре 200…400°C. Альтернативой является поддержание плазменного разряда в водороде, обеспечивающего поток атомарного водорода на стенку. На установке Ураган-3М прогрев камеры технически не возможен, поэтому использовался плазменный СВЧ-разряд с достаточной величиной плотности плазмы ($8 \cdot 10^{10}$ см$^{-3}$).

ЗМЕНШЕННЯ КОНЦЕНТРАЦІЇ ВОДИ В УСТАНОВЦІ УРАГАН-3М НВЧ-РОЗРЯДОМ

М.М. Козуля, В.Б. Коровін, О.В. Лозін, А.Ю. Красюк, Ю.К. Міронов, Р.О. Павліченко, В.С. Романов, А.Ф. Штань, С.І. Солодовченко, Д.І. Барон, А.М. Шаповал, В.Я. Чернишенко, В.К. Пашнєв і команда торсатрону Ураган-3М

Вакуумна камера установки Ураган-3М являє собою циліндр з нержавіючої сталі об'ємом ~70 м^3. Періодично вакуумна камера відкривається для напуску атмосферного тиску для проведення наукових і технічних робіт. Після її закриття та відкачування з'являється проблема, пов'язана з високою концентрацією води в залишковому газі. Для ефективного видалення парів води необхідно підтримувати стінки камери при високій температурі (200…400°C). Альтернативою є підтримка плазмового розряду у водні, що забезпечує потік атомарного водню на стінку. На установці Ураган-3М прогрів камери технічно не можливий, тому кімнатну температуру стінок камери доводиться компенсувати достатньою величиною щільності плазми ($8 \cdot 10^{10}$ см$^{-3}$) НВЧ-розряду.