HYDROGEN RECYCLING DURING RF PLASMA HEATING IN THE U-3M TORSATRON

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The hydrogen recycling behavior has been studied during the plasma experiments in torsatron U-3M. For this purpose, the time dependence of the molecular hydrogen pressure in the U-3M torsatron vacuum chamber in the modes of RF wall conditioning and RF plasma heating has been measured. The experimental results show that the hydrogen pumping from the vacuum chamber runs at constant rate during the RF discharge for each mode. After RF power switching-off the inverse desorption of hydrogen, accumulated during the RF discharge in the vacuum chamber walls and helical coil surfaces, is observed. When the antenna anode voltages and the RF pulse duration in both modes are increasing, the character of the time dependences of hydrogen pressure does not change significantly.

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INTRODUCTION

The main distinction of the Uragan-3M torsatron (U-3M) [1], as compared to other large toroidal devices designed for investigations on the plasma heating and magnetic confinement, is a large buffer volume filled with working gas. The vacuum chamber buffer volume to plasma confinement volume ratio is about 260. Thus, the buffer volume is a main source of hydrogen which enters into the plasma through the gaps between helical coils with a finite molecular conductivity. The geometry of gaps is such that they can form a partially directed molecular hydrogen flow [2]. Thus, the most part of hydrogen particles, entering through the gaps and also reflected from the inner surfaces of the helical coils, gets the plasma confinement volume where hydrogen molecules are ionized and captured. This is because the hydrogen molecule free path, at typical plasma density in the device, is much less than the cross-sectional sizes of plasma confinement volume. Hydrogen returns from the plasma into the vacuum chamber in the form of ions, charge-exchanged atoms and Franck-Condon atoms formed in the course of hydrogen molecule dissociation. The main part of hydrogen ions leaves the plasma volume along the diverted field lines that cross the side helical coil surfaces. Charge-exchanged atoms and Franck-Condon atoms hit inner surfaces of helical coils and the walls of vacuum vessel (all are made of stainless steel). Some part of these particles is absorbed by the coil surfaces and the walls, and the other part is desorbed backward into the vacuum chamber in the form of hydrogen atoms and molecules. Therefore, the molecular hydrogen pressure in the working chamber is related with both the input and output particle flows from the plasma, as well as with the hydrogen amount being absorbed and desorbed by the vacuum chamber and helical coil surfaces. By measuring the hydrogen pressure in the vacuum chamber as a function of time it is principally possible to study the hydrogen balance during active stage of discharge and afterward.

The goal of this study is to investigate the hydrogen balance in the U-3M vacuum chamber, as well as the hydrogen recycling from the walls and its influence on plasma parameters in the course of plasma experiments in the U-3M torsatron. In this paper we present the first results of measurements of hydrogen gas pressure during and just after RF power pulse used for plasma production.

EXPERIMENTAL CONDITIONS AND TECHNIQUES

In the run of experiments in the U-3M torsatron the working gas pressure was recorded with a magnetron pressure gage PMM-32 connected to vacuum gauge VMB-14. The voltage U from the analog output of the VMB-14 measuring scheme was recorded by a digital oscilloscope and then was recalculated into the value of residual pressure on the basis of calibration curves for VMB-14. Response time of the gage measuring schemes to pressure changes is $\tau \geq 5$ ms.

Duration of the unsteady gas flow phase after gas pumping startup at fixed rate was about 15…20 ms. Certified error of the gage relative pressure measurement is –30 +50 %. The pressure gage was placed in the open space on the U-3M vacuum chamber top directly over the helical coil gap.

The obtained time dependences of the pressure were processed using the standard methods of molecular vacuum technology. The time dependence of the working gas pressure in the quasi-steady operation at constant rate of gas pumping and leakage is written in the following form

$$P(t) = (P_0 - P_{end})\cdot\exp(-S*t/V) + P_{end}, \qquad (1)$$

where P(t) –is the pressure in the working chamber, t – time, S – rate of gas pumping from the working chamber at steady speed, V – working chamber volume, P_0 – starting pressure, P_{end} – end pressure when the equilibrium is observed between the rates of gas leakage and pumping in the working chamber.

RF plasma in the confinement volume was produced and heated by the use of two RF antennas operating within Alfven frequency range [3]. Investigations were carried out in two modes. The first mode is the RF plasma wall conditioning [4], the second mode is the RF plasma heating [5]. The principal parameters of the U-3M torsatron during operation were as follows: $V_{ch} \approx 65\ m^3$ is the vacuum chamber volume; $V_{pl} \approx 0.25\ m^3$ – plasma volume; $U_{apertures} \sim 3000\ m^3c^{-1}$ – estimated molecular conductivity of the helical coil gap entrance apertures for molecular hydrogen; $U_{gap} \sim 2000\ m^3c^{-1}$ – estimated total molecular conductivity of the helical coil gaps for molecular hydrogen; R=1 m – major radius; a = 0.1 m – average minor radius; $S_{ext} = 60\ m^3c^{-1}$ – rate of external hydrogen pumping from the vacuum chamber; W ~ 70…250 kW – antenna radiated RF power; U=5…9 kV – antenna anode voltage; $B_0 \sim 0.025$ T and $B_0 \sim 0.72$ T – toroidal magnetic field for the first and the second modes, respectively; $P \sim 7\cdot10^{-5}$ Torr and $P \sim 0.7\cdot10^{-5}$ Torr – initial operating hydrogen gas pressure for the first and the second modes, respectively. The basic plasma parameters for the first and the second modes were, respectively: $n_e \sim 1.5\cdot10^{18}\ m^{-3}$ and $n_e \sim 1.2\cdot10^{18}\ m^{-3}$ – average electron density in the plasma; $T_e \sim 10$ eV and $T_e \sim 100…300$ eV –average electron temperature in the plasma; $T_i \sim$ several eV and $T_i \sim 50…450$ eV – average ion temperature in the plasma.

MAIN RESULTS AND DISCUSSION

Typical time dependences of hydrogen pressure in the vacuum chamber observed during and after the plasma discharge in the modes of RF wall conditioning and RF plasma heating, are shown respectively in Fig.1 and Fig. 2 together with calculated curves describing these dependences by formula (1). As follows from the figures, the molecular hydrogen pumping during the plasma discharge occurs at constant rate of $2400\ m^3s^{-1}$ in the first mode and $1400\ m^3s^{-1}$ in the second mode. These rates are much exceeds the rate of an external pumping rate. In the first mode the rate is near the value of the helical coil gap molecular conductivity for hydrogen. Reasoning from this result it can be assumed that in this case the most part of the observed hydrogen pumping is due to gaps and internal surfaces of helical coils. The pumped hydrogen amount in the both modes is proportional to the pressure in the vacuum chamber. It indicates on the fact that the mechanism of hydrogen absorption from the vacuum chamber is related with the RF discharge activation of hydrogen pumping by the vacuum chamber and helical coil wall surfaces, as the molecular hydrogen flow onto the wall is proportional to the pressure in the chamber. Otherwise, if the pumped hydrogen amount would not change over time, the pumping rate would change with a decrease in the hydrogen pressure. However, further investigations are necessary to clear the real causes of such behavior in both modes. Besides, the fraction of atomic hydrogen in the vacuum chamber volume is unknown as it is not recorded by the pressure gage during the RF pulse.

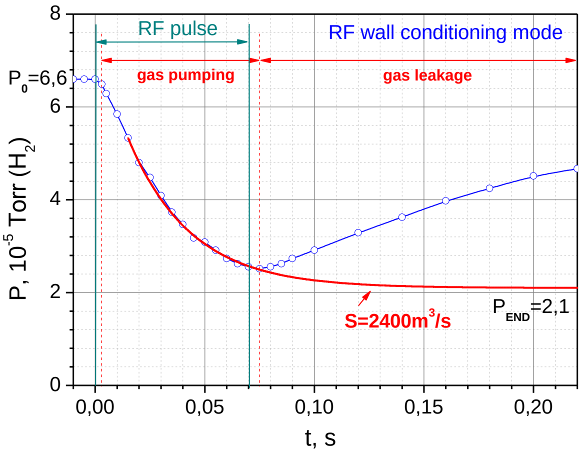

Fig. 1. Time dependences of the hydrogen pressure in the vacuum chamber during and after RF pulse in the RF wall conditioning mode. T_{RF} =50 ms – the RF pulse duration, U_1=5 kV and U_2=6 kV – anode voltages on the first (U_1) and second (U_2) RF antennas, respectively

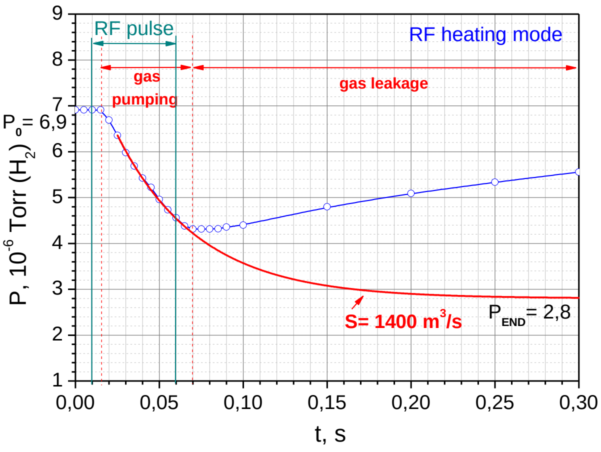

Fig. 2. Time dependences of the hydrogen pressure in the vacuum chamber during and after RF pulse in the RF heating mode. T_{RF} = 50 ms – the RF pulse duration. U_1= 9 kV – anode voltage on the first RF antenna

Figs. 1, 2 shows that after RF power switching-off in the both modes the molecular hydrogen pressure in the vacuum chamber increases at the rate exceeding the hydrogen pumping rate due to the external source $Q_{ext} = P_0 \cdot S_{ext}$ by a factor of 3.4 or 1.7 for the first and the second mode, respectively.

Oscillograms of signals with pressure sensor during and after RF pulse in RF heating mode at different anode voltages (U_1) on the first RF antenna and durations (T_{RF}) of RF pulse are shown in Fig. 3 and Fig. 4, respectively. These figures indicate that when the antenna anode voltages and the RF pulse duration in both modes are increasing, the character of the time variations of hydrogen pressure in the vacuum chamber does not change significantly. The rate of this hydrogen pumping slightly decreases with anode voltage increasing (slope of curves decreases slightly, as can be seen from Fig. 3) and does not practically depend on the RF pulse duration (in the beginning the curves coincide, as can be seen from see Fig. 4). After the RF power switched-off, a slow hydrogen pressure increase is observed, due to the hydrogen desorption from the walls and helical coil surfaces. The rate of increase does not depend on the RF pulse duration and weakly depends on the antenna anode voltages.

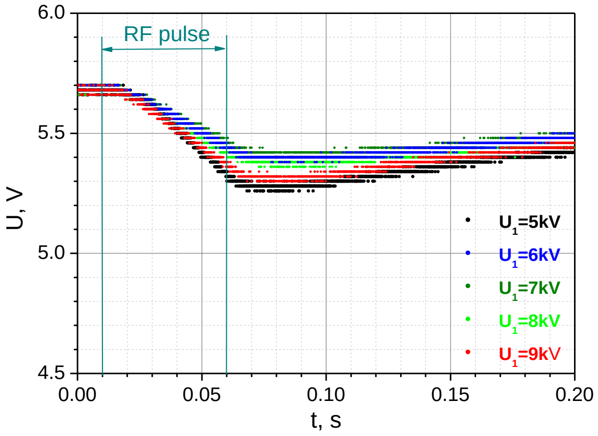

Fig. 3. Oscillograms of signals with the pressure gage during and after RF pulse in RF heating mode at different anode voltages (U_1) on the first RF antenna. T_{RF} = 50 ms is the RF pulse duration

CONCLUSIONS

The time behavior of the molecular hydrogen pressure in the vacuum chamber of the U-3M torsatron in the modes of RF wall conditioning and RF plasma heating was studied. The experimental results show that hydrogen recycling is observed in all plasma experiments. During the RF discharge for each mode the hydrogen pumping from the vacuum chamber runs at constant rate. After the power switching-off the inverse desorption of hydrogen accumulated during the RF discharge in the vacuum chamber and helical coil walls occur.

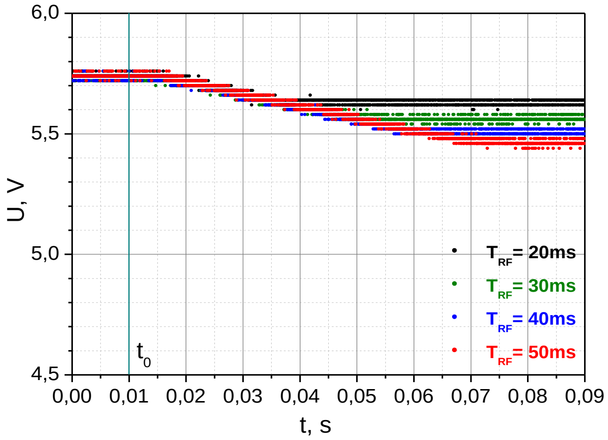

Fig. 4. Oscillograms of signals with the pressure gage during and after RF pulse in RF heating mode at different RF pulse duration (T_{RF}). U_1= 9 kV – the anode voltage on the first RF antenna, t_0 – start of the RF pulse

REFERENCES

1. V.S. Voitsenya, A.N. Shapoval, R.O. Pavlichenko, et al. Progress in stellarator research in the Kharkov IPP // *Phys. Scr*. 2014, T161, p. 014009.
2. A.A. Glaskov, G.L. Saksaganskiy. *Vacuum electrophysical installations.* M: «Energoatomizdat», 1985 (in Russian).
3. O.M. Shvets, I.A. Dikij, S.S. Kalinichenko, et al. // *Nucl. Fusion.* 1986, v. 26, p. 23.
4. A.V. Lozin, V.E. Moiseenko, L.I. Grigor'eva, et al. // *Fizika plazmy*. 2013, v. 39, p. 704 (in Russian).
5. V.V. Chechkin, L.I. Grigor'eva, M.S. Smirnova, et al. // *Fisika plasmy*. 2014, v. 40, p. 697 (in Russian).

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РЕЦИКЛИНГ ВОДОРОДА ВО ВРЕМЯ ВЧ-НАГРЕВА ПЛАЗМЫ В ТОРСАТРОНЕ У-3М

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Изучено поведение рециклинга водорода во время плазменных экспериментов на торсатроне У-3М. Для этой цели было проведено измерение временных зависимостей давления водорода в вакуумной камере торсатрона У-3М в режимах ВЧ-чистки стенок камеры и ВЧ-нагрева плазмы. Экспериментальные результаты показали, что в обоих режимах во время ВЧ-разряда скорость откачки водорода из вакуумной камеры остается постоянной для каждого из режимов. После выключения ВЧ-мощности наблюдается обратная десорбция водорода, накопленного во время ВЧ-разряда в стенках вакуумной камеры и винтовых катушек. Повышение анодных напряжений на ВЧ-антеннах и увеличение длительности ВЧ-импульса существенно не влияют на характер временных зависимостей давления водорода.

РЕЦИКЛІНГ ВОДНЮ ПІД ЧАС ВЧ-НАГРІВУ ПЛАЗМИ В ТОРСАТРОНІ У-3М

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Вивчено поведінку рециклінгу водню під час плазмових експериментів на торсатроні У-3М. Для цієї мети було проведено вимірювання часових залежностей тиску водню у вакуумній камері торсатрона У-3М в режимах ВЧ-чистки стінок камери і ВЧ-нагріву плазми. Експериментальні результати показали, що в обох режимах під час ВЧ-розряду швидкість відкачування водню з вакуумної камери залишається постійною для кожного з режимів. Після виключення ВЧ-потужності спостерігається зворотна десорбція водню, накопиченого під час ВЧ-розряду в стінках вакуумної камери і гвинтових котушок. Підвищення анодних напруг на ВЧ-антенах і збільшення тривалості ВЧ-імпульсу істотно не впливають на характер тимчасових залежностей тиску водню.