METHODS FOR MEASURING HYDROGEN BALANCE IN VACUUM CHAMBER OF U-3M TORSATRON DURING PLASMA EXPERIMENTS

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The experimental method was developed for evaluation of a hydrogen particle flux balance over a wide range of operating conditions in the Uragan-3M torsatron (U-3M) in the course of RF discharges. Standard pressure gauges were tested for measurement of non-stationary hydrogen pressure in the U-3M vacuum chamber. The average lifetime of hydrogen ions was determined for each operation mode of U-3M.

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INTRODUCTION

An experimental study of a hydrogen particle balance has been carried out with standard pressure gauges over a wide range of operating conditions in the U-3M torsatron [1-3]: I – a mode of RF plasma heating with a magnetic field $B_0 \sim 0.7$ T, hydrogen pressure $P \sim 7\times10^{-6}$ Torr, average plasma density $\langle n_e\rangle \sim 1\times10^{12}$ cm^{-3}, ion and electron temperature $T_{e,i} \approx$ (200…600) eV, RF pulse length of (10…50) ms; II – a mode of RF wall conditioning with a magnetic field $B_0 \sim 0.7$ T, hydrogen pressure $P \sim 4.5\times10^{-5}$ Torr, average plasma density $\langle n_e\rangle \leq 8\times10^{12}$ cm^{-3}, ion and electron temperature $T_{e,i} \leq 20$ eV, RF pulse length of (10…50) ms; III – a mode of RF wall conditioning with a weak magnetic field $B_0 \sim 0.024$ T, hydrogen pressure $P \approx 1.3\times10^{-4}$ Torr, average plasma density $\langle n_e\rangle \sim 1.5\times10^{12}$ cm^{-3}, ion and electron temperature $T_{e,i} \leq 20$ eV, RF pulse length of ~50 ms. The temporal behavior of the hydrogen pressure in the vacuum chamber of U-3M during main operation modes is described in [4].

Two types of standard pressure sensors are used for the measurement in the U-3M vacuum chamber. The first type is the magnetron sensor PMM-32. The second type is the ionization sensor PMI-2. The ionization sensors have better inertial properties during measurement of non-stationary pressure. This allows to measure the behavior of pressure with temporal resolution of a few tens of microseconds. Such sensors are widely used in various research installations where experiments on plasma confinement and heating [5] are provided. They are usually fabricated and calibrated individually for each installation taking into account specific experimental conditions. In our case with non-stationary magnetic fields, intensive interference from RF antennas, and fluxes of charged particles to the walls of the vacuum chamber of the U-3M torsatron, the standard ionization sensors have not to be used. The magnetron sensors are less sensitive to external interference but they have much longer temporal inertia**.** This is due to the long time changes of magnetron discharge parameters during pressure variations. Therefore, to measure correctly the non-stationary pressure using such sensors, it is necessary to develop the measurement technique which compensates their temporal inertia.

1. MEASUREMENT OF NON-STATIONARY PRESSURE

Locations of the magnetron pressure sensors PMM-32 inside the U-3M vacuum chamber are shown schematically in Fig. 1. One sensor is installed on the roof of the vacuum chamber at a distance of 2 m above helical coils. This sensor measures the pressure in the main volume of the vacuum chamber. The second sensor is installed on the upper end of a vertical tube with an internal diameter of 24 cm and a length of 1.9 m. The lower open end of the tube is located in the gap between helical coils. The pressure measured by the second sensor depends on the pressure near the plasma. This pressure, in turn, is caused by a molecular hydrogen flux through gaps between helical coils from the main volume of the vacuum chamber and by hydrogen desorption from internal surfaces of helical coils.

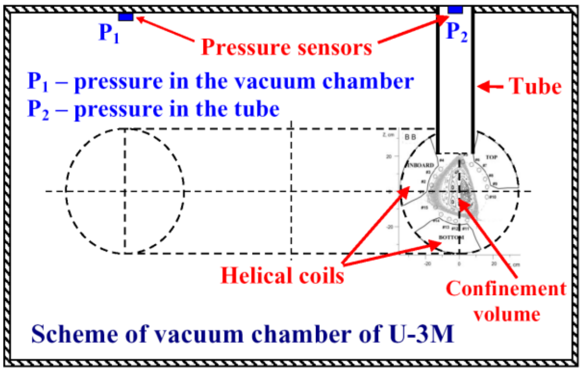

Fig. 1. Location of pressure sensors PMM-32 inside the vacuum chamber of the U-3M torsatron

Pumping out of hydrogen from the vacuum chamber during the RF discharge occurs due to absorption on chamber walls of hydrogen atoms and ions leaving the plasma. The pumping out rate of hydrogen from the vacuum chamber cannot exceed a total value of molecular conductivity of all gaps between helical coils $U_{gaps} \approx 2100$ m^3/s because they restrict the hydrogen flux into the plasma. Most of the molecular hydrogen that flows through the gaps between helical coils is absorbed by plasma in the confinement volume for two reasons. Firstly, the free path length of hydrogen molecules in the confined plasma is much smaller than cross-sectional sizes of a plasma column. Secondly, the hydrogen flux is considerably overlapped by the plasma column at an exit from the gaps. This assumption is derived from the spatial distribution of molecular fluxes leaving the gap with the given cross-section, according to [6].

The condition for the existence of a quasi-stationary gas flux through the gaps between helical coils is performed in all main operation modes:

$$\frac{V}{S}\cdot\frac{U}{LA}>>1, \quad (1)$$

where V is the pumped volume, S is the pumping out rate from the pumped volume through the pipeline with a molecular conductivity U, a length L and a cross-section A. Consequently, the temporal behavior of hydrogen pressure in the U-3M vacuum chamber can be described by a simple expression from a vacuum technique, as follows:

$$P(t)=\left(P_0-P_{END}\right)\exp\left(\frac{-St}{V}\right)+P_{END}, \quad (2)$$

where $P(t) = nkT$ is the pressure in the vacuum chamber; t – time; n – concentration of molecules; T – gas temperature; k – Boltzmann constant; P_0 – initial pressure. P_{END} is an equilibrium pressure, which is set in the vacuum chamber, when the equality is fulfilled between the rate of leakage from the walls and the pumping out rate S from the chamber volume.

Condition (1) is not performed for the tube. The gas pumping out rate from the tube volume is time-dependent and during the RF pulse length is changing from zero to some value that cannot exceed the value of molecular conductivity of the tube U_{tube} = 2.1 m^3/s. The temporal behavior of the pressure, in this case, is determined by the hydrogen flux balance in the open end of the tube. Such task is solved analytically in [7]. Numerical methods to solve similar tasks [6] can also be used with regard to complex vacuum systems. In our case, in order to describe the temporal behavior of the pressure in the tube, one has to know the spatial distribution of the flux of hydrogen particles that bombard the internal surface of the tube. Formula (1) can be used for qualitative estimation of the average pumping rate from the tube. However, the pumping out rate S determined from (1) in this case will be the equivalent average rate which characterizes the pressure change during the whole RF pulse time.

The calibration of magnetron sensors PMM-32, based on readings of the ionization sensor PMI-2, was performed before the start of measurement of the hydrogen balance in the U-3M vacuum chamber. The ionization sensor was installed on the roof of the vacuum chamber nearby to the magnetron sensor. The pressure in the vacuum chamber was related to readings from magnetron sensors by the following expression: $P = exp((U - b)/\gamma)$, where P is a pressure in Torr, U is a voltage in volts on the analogue output of the measurement unit VMB-14, b and γ are the coefficients of proportionality, which are determined experimentally for each sensor, based on the calibration curves.

It was found that the response time of the magnetron sensor to the pressure changes was about (3…5) ms. The time dependences of the pressure measured by sensors PMI-2 and PMM-32 on the roof of the vacuum chamber during a pulsed hydrogen puff are shown in Fig. 2. In a case of the magnetron sensor the equation (2) includes the time constant τ which takes into account the time inertia of the sensor. The pumping out rates S determined from the readings of both sensors are close to each other. The calculation is based on modified equation (2) shown in Fig. 2. The figure also shows that the amplitudes of the pressure change, measured by both sensors, are of similar value.

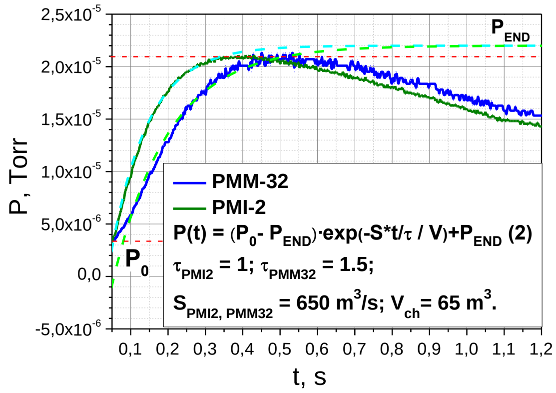

Fig. 2. Time dependences of hydrogen pressure measured by the PMM-32 and PMI-2 sensors on the roof of the vacuum chamber during a pulsed hydrogen puff. Approximation curves calculated from modified expression (2) for each sensor are shown as dotted lines

Sensor readings behaved differently during a fast pressure drop in the vacuum chamber. With pumping out rates comparable to those of outer pump line there was no essential signal delay for the magnetron sensor PMM-32 in relation to ionization sensor PMI-2. Fig. 3 shows the time dependences of pressure measured by ionization and magnetron sensors on the roof of the vacuum chamber during a fast pumping process with the rate exceeding considerably the pumping out rate of the outer pump line. As it is clear from Fig. 3, pressure change amplitudes measured by both types of sensors are also the same. However, for the magnetron sensor there is a delay of readings in time. The time inertia of the magnetron sensor in this case is revealed in overestimation of the end equilibrium pressure P_{END} determined from equation (2). The pumping rates for both sensors, determined from equation (2), correspond to each other. The time dependence of pressure measured by the ionization sensor PMI-2 during RF pulse has a drop caused by effect of RF interference and charged particles bombarding the sensor casing.

When RF power is off, the readings of the ionization sensor PMM-32 return to normal values within the following 20 ms. The pumping stage is completed at some moment after the switch-off of RF power. Starting from this moment, hydrogen pressure increases in the vacuum chamber. This increase is caused by hydrogen desorption from the walls and external leakage.

The rates of hydrogen leakage determined from the readings of both sensors are also almost the same. However, at the stage of pressure increase, magnetron sensor readings indicate a delay of 150 ms in time with regard to ionization sensor readings. This peculiarity should be taken into account during processing the experimental dependences of hydrogen pressure in time.

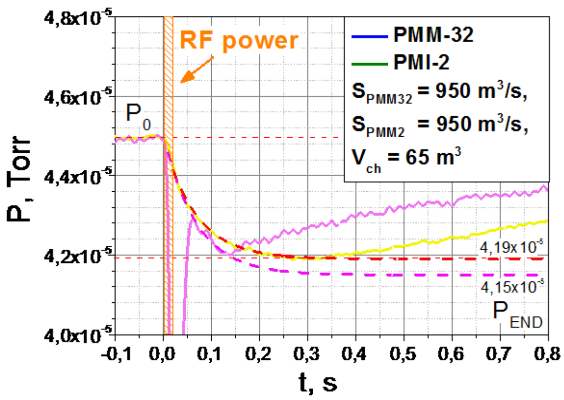

Fig. 3. Time dependences of hydrogen pressure in the vacuum chamber measured by the magnetron sensor PMM-32 and the ionization sensor PMI-2 during and after the RF discharge. Approximation curves calculated from expression (2) for each sensor are shown in dotted lines

2. HYDROGEN BALANCE IN VACUUM CHAMBER OF U-3M TORSATRON

The hydrogen flux into the confined plasma from the U-3M vacuum chamber during the RF discharge is defined by molecular conductivity of gaps between helical coils. By measuring the average pumping out rate of hydrogen from the U-3M vacuum chamber during the RF discharge one can determine the pressure difference between the outside and the inside boundary of the gaps. The pressure behind the gap near the plasma P^* is related to the pressure in the vacuum chamber P_{ch} by the following ratio:

$$P^* = \beta P_{ch},\ \beta = \frac{U - (\langle S\rangle - S_{pump})}{U}, \qquad (3)$$

where $\langle S\rangle$ is the average pumping out rate of hydrogen from the vacuum chamber during the RF discharge; β – the transparency coefficient of gaps; $U = 2100$ m^3/s – the total molecular conductivity of all gaps between the helical coils; $S_{pump} = 60$ m^3/s – the pumping out rate of outer pump line. The pressure $P*$ can be considered as the average pressure along the outer perimeter of the plasma. This pressure is created behind gaps by the direct flux of hydrogen molecules from the vacuum chamber, molecules scattered at the lateral and inner surfaces of the helical coils, molecules, which flow between helical coils and the plasma, and by a reverse desorption of hydrogen molecules from the inner side walls and helical coils. As has been shown in [4], the temporal behavior of the hydrogen in the U-3M vacuum chamber during RF pulse is described by expression (2).

The average flux of hydrogen molecules $\langle J_{H2}\rangle$ into the plasma during RF pulse length Δt_{RF} can be estimated from two relations, which are approximately equal to each other:

$$\langle J_{H2}\rangle = \frac{\langle J_{ch}\rangle}{1-\alpha},\ \langle J_{H2}\rangle = \frac{1}{4}\bar{v}_{H2}\langle n^*_{H2}\rangle A_{pl}, \qquad (4)$$

where $\langle J_{ch}\rangle = \langle n_{H_2}\rangle(\langle S\rangle - S_{pump})$ – the average flux of hydrogen pumped out from the vacuum chamber during the RF discharge due to absorption on the walls; $\langle n_{H_2}\rangle \approx (n_0 - \Delta n_{H_2}/2)$ – the average concentration of hydrogen molecules in the vacuum chamber during the RF discharge; n_0 – the initial concentration of hydrogen molecules in the vacuum chamber before the RF pulse, n_{H_2} – the concentration of hydrogen molecules in the vacuum chamber at the time moment t; Δn_{H_2} – the change of the concentration of molecular hydrogen in the vacuum chamber during the RF discharge; $n^*_{H_2} = \beta n_{H_2}$ – the concentration of hydrogen molecules behind the gaps near the plasma at the moment t; $\langle n^*_{H_2}\rangle = \beta\langle n_{H_2}\rangle$ – the average concentration of molecular hydrogen behind the gap near the plasma during the RF discharge; $V_{ch} = 65$ m^3 – the vacuum chamber volume; $\alpha = 2J^{Re}_{H_2}/(J_{H+} + J_H)$ – the coefficient of reverse hydrogen desorption from walls bombarded by atoms and ions of the plasma; $J^{Re}_{H2} = (\langle S\rangle n_{H2\ END} - S_{pump}n_0)$ – the average reverse flux of hydrogen molecules from walls into the vacuum chamber; $n_{H2\ END} = P_{END}/(kT)$ – the equilibrium concentration of hydrogen from the expression (2); $J_{H+} = V_{pl}\, n_e/\langle\tau\rangle$ – the average flux of hydrogen ions from the plasma to the walls; J_H – the average flux of hydrogen atoms from the plasma to the walls; n_e – the average plasma density in a confinement volume during the RF discharge; $\langle\tau\rangle$ – the average lifetime of hydrogen ions in a confinement volume during the RF discharge; $\bar{v}_{H_2} = (8kT/\pi/m_{H_2})^{1/2}$ – the average thermal velocity of hydrogen molecules; m_{H_2} – the mass of a hydrogen molecule; $A_{pl} = 4\pi^2 aR \approx 4$ m^2 – the area of a plasma surface with the small and the large radii $a = 10.4$ cm and $R = 1$ m, respectively, according to [8]; $V_{pl} = 0.213$ m^3 – the volume of plasma confinement. The first expression in (4) defines the average hydrogen flux into the confined plasma during the RF discharge, which is measured from the amount of hydrogen pumped out from the vacuum chamber. The second expression in (4) defines the molecular hydrogen flux through the outer boundary of the plasma. If we neglect the hydrogen desorption from walls, then $J_{H+}+J_H \approx 2\langle J_{H_2}\rangle$. As a result, $\alpha \approx J^{Re}_{H_2}/\langle J_{H_2}\rangle = J^{Re}_{H_2}/(\langle J_{ch}\rangle + J^{Re}_{H_2})$.

In a quasi-stationary case, when the plasma parameters in a confinement volume are slightly varying with time, the approximate balance of the hydrogen in a chamber volume during the RF discharge duration can be written, as follows:

$$V_{ch}\frac{2\Delta n_{H2}}{\Delta t_{RF}} \approx -(1-\alpha)(J_{H+}+J_{H}) + \frac{V_{pl}\Delta n_e}{\Delta t_{RF}} +$$

$$+2\left[Q_{wall\,puff} - Q_{wall\,pumping} + Q_{gas\,puff} - Q_{pump}\right], \quad (5)$$

where $Q_{gas.puff} = S_{pump}n_0$ – the external hydrogen puff into the vacuum chamber; $Q_{pump} = S_{pump}n_{H_2}$ – pumping out of the pump from the vacuum chamber; $Q_{wall\,pumping}$ – wall pumping of hydrogen from the vacuum chamber; $Q_{wall\,puff}$ – the hydrogen desorption from walls; Δn_e – a change of the average plasma density during the RF discharge. An influence of radiation from the plasma on desorption of hydrogen molecules from the walls in this expression is not considered. Since during all operating modes the ion and atom fluxes greatly exceed the values of all other terms of the right-hand side of expression (5), this expression can be simplified. Namely, neglecting in (5) the terms of the smaller orders in values we can estimate the average lifetime $\langle\tau\rangle$ of hydrogen ions in the plasma confinement volume during the RF pulse length Δt_{RF} from the following expression:

$$\langle\tau\rangle \approx -(1+K)(1-\alpha)\left[\frac{V_{pl}n_e}{V_{ch}2\Delta n_{H_2}}\right]\Delta t_{RF}, \quad (6)$$

where $K = J_H/J_{H+}$ – the calculated ratio of the atomic J_H and ionic J_{H+} flux from the plasma. This expression is correct if the ionization, charge-exchange and dissociation of hydrogen particles do occur in the volume of plasma confinement.

The results of Langmuir probe measurement of plasma parameters outside of the plasma confinement volume [9] and large enough average lifetimes of hydrogen ions in the plasma $\tau \geq 1$ ms, according to our estimates from (6), evidence the validity of such assumptions. Otherwise, the average lifetime of ions outside the plasma would be much smaller, as the lifetime of ions outside the confinement volume is defined by the time of flight of the ions to the walls along the open magnetic field lines and does not exceed (10…20) microseconds. In the case, where additional ionization of the working gas occurs outside the confinement volume, $\langle\tau\rangle$ will characterize the average lifetime of ions in all areas where ionization occurs.

The coefficient K can be evaluated qualitatively from the rates of reactions and the average plasma density for each mode. In the first mode, the electron temperature and plasma density are $T_e \leq (200…600)$ eV and $n_e \leq 2\times10^{12}$ cm^{-3}, respectively. In such a case the hydrogen molecules entering into the plasma through outer boundary are ionized to form molecular ions H_2^+, which then immediately dissociate into ions H^+ and atoms H, due to the high rates of ionization $\langle\sigma_{H2+}v\rangle \sim (4…5)\times10^{-8}$ cm^3·s^{-1} and dissociation $\langle\sigma_{dis\,H2+}v\rangle \sim 1.2\times10^{-7}$ cm^3·s^{-1}, according to [10, 11]. The free path length of hydrogen molecules in the plasma does not exceed ~5 cm, i.e., $\lambda << 2a$. The dissociation rate of hydrogen molecules, $\langle\sigma_{H_2}v\rangle < 9\times10^{-9}$ cm^3·s^{-1}, is 4…5.5 times lower than the rate of ionization. That is, dissociation of hydrogen molecules in the plasma can be neglected. The ionization rate of hydrogen atoms $\langle\sigma_{H+}v\rangle = (2.2…3.1)\times10^{-8}$ cm^3·s^{-1} is almost 2 times less than the ionization rate of molecules. The kinetic energy of dissociated slow atoms (Franck-Condon atoms) is $E = (3…10)$ eV. At these energies, the average concentration of slow atoms in the plasma column will be much lower than the average concentration of the molecules. Therefore, the ionization of atoms in the plasma can also be neglected. The flux of fast charge-exchange atoms with the kinetic energies $E > 100$ eV depends on the concentration of slow hydrogen atoms in the plasma. In turn, the concentration of slow hydrogen atoms in the plasma is determined by dissociation of molecular ions and also atoms reflected from the walls. Because of gaps between helical coils and since the reflection coefficient of atoms and ions from the walls does not exceed ~60 %, the concentration of reflected atoms in the plasma is 2…3 times lower than the concentration of atoms produced by dissociation of molecular ions. Therefore, the contribution of reflected atoms in the ionization process in the plasma can also be ignored. All other processes in the plasma were negligible. In view of the above, it can be expected that the ratio between the flux values of atoms and ions from the plasma in the first mode $K \sim 1$.

The averaged flux densities of hydrogen particles at the plasma boundary in the case of the first mode are shown in Fig. 4. These fluxes were computed with the programming code KN1D [12]. In the model, used at the quasi-stationary stage of the RF discharge, the flux density of H_2 molecules entering the plasma through its boundary surface is balanced by the total density of hydrogen particle fluxes leaving the plasma. The leaving fluxes consist of H^+ ions and neutrals: slow H_L atoms and fast charge-exchange H_{CX} atoms. Other fluxes were negligible. These results do not contradict to the estimates presented above.

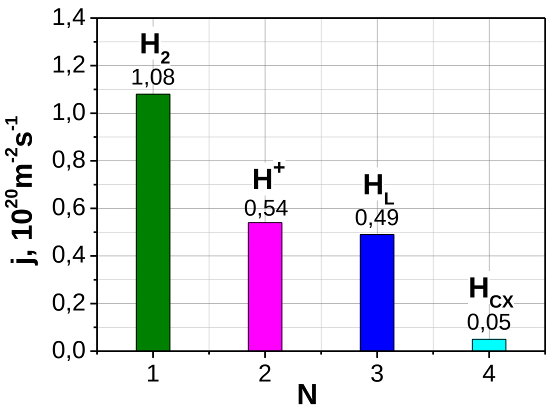

Fig. 4. The calculated averaged flux densities j of hydrogen particles at the plasma boundary in the first operation mode. №1 – flux density of hydrogen molecules into the plasma; №2 – flux density of hydrogen ions from the plasma; №3 – flux density of slow hydrogen atoms from the plasma; №4 – flux density of fast CX atoms from the plasma

In both, the second and third modes, the electron temperature is $T_e \leq 20$ eV. At these electron temperatures the rates of processes mentioned above are [10, 11]: $\langle\sigma_{disH_2^+}v\rangle \sim 10^{-7}$ cm^3·s^{-1}; $\langle\sigma_{H_2^+}v\rangle \sim 2\times10^{-8}$ cm^3·s^{-1}; $\langle\sigma_{H_2^+}v\rangle = 1.4\times10^{-8}$ cm^3·s^{-1}; $\langle\sigma_{H_2}v\rangle \sim 9\times10^{-9}$ cm^3·s^{-1}. As can be seen from these values, the dissociation of hydrogen molecules and molecular hydrogen ions create approximately the same amount of slow atoms in the plasma. In the second mode, the plasma density is $n_e \le 8\times10^{12}$ cm^{-3}. At this density, the free path length of hydrogen atoms becomes comparable with the transverse dimension of the plasma column $\lambda \sim 2a$. Therefore, the ionization of atoms begins to change significantly the balance of hydrogen particles in the plasma, increasing the ionic flux from plasma. In the third mode, the ionization of atoms can be neglected. The typical plasma density for this mode is $n_e \le 1.5\times10^{12}$ cm^{-3}. Based on the foregoing, it can be expected that in the second mode $1 < K \le 2$, and in the third mode $K \sim 2$.

By measuring the temporal behavior of hydrogen pressure in the U-3M vacuum chamber we evaluated the average lifetime of hydrogen ions in confined plasma for each operation mode. These times were: in the first mode $\langle\tau\rangle = (1…3)$ ms, in the second mode $\langle\tau\rangle = (10…20)$ ms, in the third mode $\langle\tau\rangle \sim 150$ μs.

CONCLUSIONS

A technique was developed to process the temporal dependences of hydrogen pressure measured by standard pressure sensors in the U-3M vacuum chamber during plasma experiments. The obtained relations allow to estimate the average lifetime of ions in the confined plasma, the hydrogen pressure near the plasma, as well as the value of reverse hydrogen desorption from the walls of the U-3M vacuum chamber during RF discharges. The lifetime of hydrogen ions in the confined plasma was estimated for main operating modes of U-3M.

REFERENCES

1. A.V. Lozin, V.E. Moiseenko, et al // *Fizika plazmy*. 2013, v. 39, p. 704 (in Russian).
2. V.V. Chechkin, L.I. Grigor'eva, et al. // *Fisika plazmy*. 2014, v. 40, p. 697 (in Russian).
3. A.V. Lozin, V.E. Moiseenko et al // *Problems of Atomic Science and Technology. Series “Plasma Physics”* (83). 2013, № 1, p. 27.
4. V.K. Pashnev, A.A. Petrushenya et al // *Problems of Atomic Science and Technology. Series “Plasma Physics”* (20). 2013, № 6, p. 272.
5. A. Niemczewski, B. Lipschultz, et al. // *Review of Scientific Instruments.* 1995, v. 66 (1), p. 360.
6. A.A. Glazkov, G.L. Saksaganskiy. *Vacuum of electrophysical installations*. Moscow: “Energoatom-izdat”, 1985 (in Russian).
7. G.A. Tjagunov. *The basis of calculation of vacuum systems*. Moscow: “Gosenergoizdat”, 1948 (in Russian).
8. V.K. Pashnev, I.K. Tarasov et al // *Problems of Atomic Science and Technology. Series “Plasma Physics”* (83). 2013, № 6, p. 15.
9. A.A. Kasilov, L.I. Grigor'eva et al // *Problems of Atomic Science and Technology. Series “Plasma Physics”* (21). 2015, № 1, p. 95.
10. R.K. Janev, D. Reiter and U. Samm. Report Juel-4105, Forschungszentrum Juelich, Germany, Dec. 2003, p. 190.
11. R.K. Janev, J.J. Smith. Cross sections for collision processes of hydrogen atoms with electrons, protons and multiply charged ions // *Atomic and Plasma – Material Interaction Data for Fusion*, v. 4, IAEA, Vienna.
12. B. LaBombard. KN1D: A 1-D space, 2-D velocity, kinetic transport algorithm for atomic and molecular hydrogen in an ionizing plasma (tech. rep. PSFC-RR-01-3), Cambridge, 2001.

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МЕТОДИКИ ИЗМЕРЕНИЯ БАЛАНСА ВОДОРОДА В ВАКУУМНОЙ КАМЕРЕ ТОРСАТРОНА У-3М ВО ВРЕМЯ ПЛАЗМЕННЫХ ЭКСПЕРИМЕНТОВ

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Разработана экспериментальная методика оценки баланса потоков частиц водорода во время ВЧ-разрядов в торсатроне Ураган-3М (У-3М) в широком диапазоне рабочих параметров. Для измерения нестационарного давления водорода в вакуумной камере У-3М были апробированы стандартные датчики давления. Для каждого из рабочих режимов работы У-3М было определено среднее время жизни ионов водорода.

МЕТОДИКИ ВИМІРЮВАННЯ БАЛАНСУ ВОДНЮ У ВАКУУМНІЙ КАМЕРІ ТОРСАТРОНА У-3М ПІД ЧАС ПЛАЗМОВИХ ЕКСПЕРИМЕНТІВ

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Розроблено експериментальну методику оцінки балансу потоків частинок водню під час ВЧ-розрядів у торсатроні Ураган-3М (У-3М) в широкому діапазоні робочих параметрів. Для вимірювання нестаціонарного тиску водню у вакуумній камері У-3М були апробовані стандартні датчики тиску. Для кожного з робочих режимів У-3М було визначено середній час життя іонів водню.