ON THE ISSUE OF SHIELDING PROPERTIES OF PLASMA IN THE OUTSIDE SEPARATRIX REGION OF U-3M

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When providing experiments on RF plasma production and heating in U-3M torsatron there was observed sudden decrease (up to two times) of mean confined plasma density during step-rise of an RF antenna voltage. Trying to analyze the reason of this effect we estimated a screening effect of the out-separatix plasma, characteristics of which were recently measured. It was found that at the plasma confinement border the attenuation is: 6 % for H_2, 1.4, 7, 6 % for C, Fe and Ti atoms correspondingly. This is much below the result of attenuation (~70 %) estimated in [1] for the flux of laser ablated C atoms.

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INTRODUCTION

In the l = 3 Uragan-3M (U-3M) torsatron, the hydrogen plasma is produced and heated by supplying RF power in the frequency range $\omega \leq \omega_{ci}$ to two unshielded antennas located close the boundary of plasma confinement volume: a frame type (FT) antenna and a three-half-turn (THT) antenna. A very specific feature of U-3M, distinguishing it from many other fusion devices, is that the whole magnetic system is placed inside a large vacuum tank, thus the ratio of plasma volume to a gas filled volume is ~1/200. Due to such construction, an open natural helical divertor configuration is realized with plasma confinement volume major radius R_0 = 1 m and average plasma radius $a \approx$ 0.12 m. The inner radius of helical coil casings is 19 cm, and just these casings play the main role of the first wall for confined plasma. Working gas pressure (hydrogen) $\approx 5 \cdot 10^{-6}$ Torr.

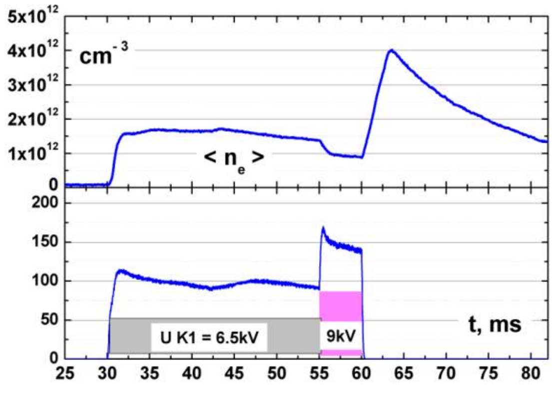

Fig. 1. Time behavior of mean plasma density (upper oscillogram) and anode voltage supplied to FT antenna (lower oscillogram)

In the course of experiments it was found out that any sudden fast rise of RF power during the discharge by stepwise-like increase of an anode voltage, e.g., from ~6.5 by ~9 kV, results in a significant drop (factor 1.5-2.0) of mean plasma density (measured by a microwave interferometer), instead of ex ante density increase. Fig. 1 demonstrates the corresponding oscillograms.

One possible explanation of this phenomenon–the decrease of hydrogen inflow due to increase of its ionization in a near-separatix plasma. Such a viewpoint was mentioned long time ago [1], when discussing the results of pulsed impurity injection by laser ablation of a graphite target placed at the helical coil casing. As the reason of protection from injected C atoms the authors considered the divertor plasma layer, i.e., the region which includes ergodic and divertor field lines with total radial dimension ≈5 cm, although at that time there were no data about plasma characteristics in the space between casing and plasma confinement volume.

Using the ratio of intensities of lines CV / CII when increasing the flux of injected atoms and suppose that at high total flux of carbon atoms ($>10^{17}$) the periphery plasma temperature decreases resulting in an increase of a penetrability, the screening ability was estimated as ≈0.7 from the level of injection.

1. ASSESSMENT OF SCREENING EFFICIENCY

In the present paper we are trying to answer the question about screening efficiency of the out-separatrix plasma region for penetration of H_2 molecules coming from the space outside plasma confinement volume through wide slits between helical coils, and H_2 molecules, C, Fe, and Ti atoms coming from helical coil casings. When considering a one-dimensional model for penetration of indicated atoms and molecules, the data on n_e and T_e spatial distributions in the space between helical coil casings (19 cm) and the last closed magnetic surface (10 cm in the cross section where measurements were done) obtained from electric probe measurements were used for the estimations. The raw data of probe measurements of n_e outside plasma confinement volume are shown in Fig. 2 (Note that the value of $n_e = 2 \cdot 10$ cm^{-3} near the last closed magnetic surface, r=10 cm, was very close to what was accepted in [1]).

As for $T_e(r)$ distribution, after some simplification of results of probe measurements, within accuracy ±5 eV it can be accepted as 30 eV in the interval 19…12 cm, 40 eV at r=11 cm and 55 eV at r=10 cm.

Toroidal magnetic field B_t was 0.72 T as distinct from experiments in [1] provided within magnetic field strength 0.46 T.

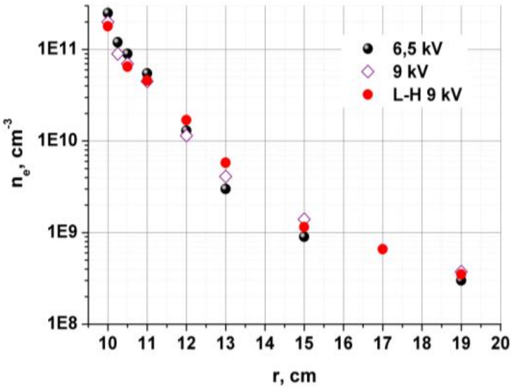

Fig. 2. Spatial distribution of plasma electron density outside plasma confinement volume at anode voltages 6.5 and 9 kV, and during L-H transition at 9 kV

2. ATTENUATION OF H_2 FLUX FROM THE VESSEL VOLUME

The most important processes can be characterized by the use of data from the paper by Harrison [2]. For H_2 molecule disintegration at the T_e range T_e=2…100 eV the following processes have to be taken into account:

$e + H_2 \rightarrow H + H + e$ - [dissociation]; (1)
$e + H_2 \rightarrow H_2^+ + 2e$ - [ionisation]; (2)
$e + H_2 \rightarrow H^+ + H + 2e$ - [dissociative ionisation]. (3)

The formula for flux attenuation is:

$$\Gamma_r = \Gamma_o \exp\{-\int n_e(r)dr\left(\frac{k_1+k_2+k_3}{\upsilon_{H2}}\right)\} ,$$

where k_1, k_2, k_3 – are the rate coefficients for processes 1, 2, 3 from [2].

The results of calculation of relative attenuation of H_2 flux are shown in Fig. 3.

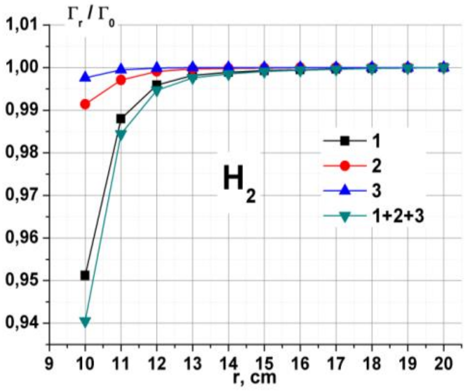

Fig. 3. Relative attenuation of H_2 molecular flux due to disintegration under the influence of processes 1, 2, 3 and their sum (1+2+3)

One can see that the relative attenuation for indicated processes amounts: 1 – 4.9%, 2 – 0.9%, and 3 – 0.25%, i.e., ~6% in total.

3. ATTENUATION OF PARTICLE FLUXES FROM HELICAL COIL CASINGS

The plasma-wall interaction will result in generation of a reverse flow of hydrogen and impurities (C, Fe, Ti) to the plasma confinement volume. For making any estimation of penetration of these particles, important is the knowledge of their velocity when leaving the wall surface. Let's compare the data from different sources. The authors of paper [3] have found, when modeling behavior of hydrogen neutrals in TFTR aiming to clear up its behavior in ITER, that the peak of energy distribution of particles sputtered under bombardment of walls by fluxes of H, D, T, C with energies 100, 500, 1000, and 3000 eV, correspondingly, falls on 7.2 eV.

In the paper [4] the velocities were found from measured Doppler contours.

Data from both these papers are presented in the Table.

The velocities of the incident particles (in cm / s)

Reference	υ_{H2}	υ_C	υ_{Fe}	υ_{Ti}
[3]	$2.6 \cdot 10^6$	$1 \cdot 10^6$	$1 \cdot 10^6$	$7.9 \cdot 10^5$
[4]	-	$7.4 \cdot 10^5$	$5 \cdot 10^5$	$5 \cdot 10^5$

As follows, there are no big differences of these data. For impurities we gave preference to data from [4], and the estimated attenuation of them is: C – 1.4%, Fe – 7%, Ti – 6% (Fig. 4).

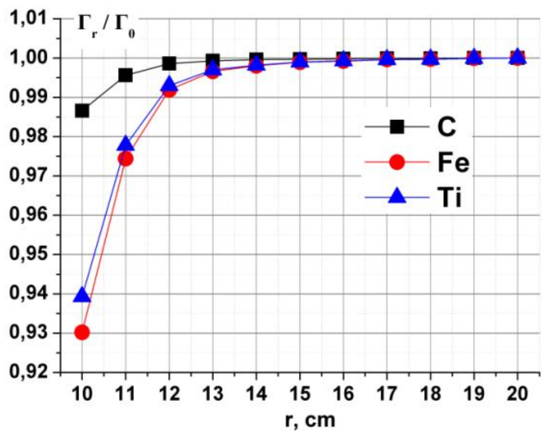

Fig. 4. Relative attenuation of C, Fe, and Ti atom fluxes on the way from casing to plasma boundary

If one supposes that C atoms have the velocity corresponding to room temperature, (e.g., from CH_4), the attenuation factor at the edge of plasma confinement volume will be ≈14 %.

CONCLUSIONS

From the above presented data the following conclusive remarks can be drawn out:

1. In investigated U-3M RF discharges the characteristics of out-separatrix plasma cannot provide any significant attenuation of hydrogen or impurity atom fluxes on the way to plasma confinement volume.
2. Therefore, the drop of plasma density during stepwise RF power increase cannot be explained by existence of dense plasma in the out-separatrix volume.
3. Significant attenuation could take place only with plasma density near the last magnetic surface at the level $\geq 1\cdot 10^{12}$ cm^{-3}, if distributions of out-separatix plasma characteristics will be similar to described above.
4. The possible reason for observed drop of a mean plasma density can be the recently disclosed effect of strong decrease of hydrogen pressure in the U-3M tank during RF pulse [5].

REFERENCES

1. V.L. Berezhniy, V.S. Voitsenya, Ja.Fh. Volkov, et al. *Experiments on laser injection of impurity atoms on torsatron Uragan -3*: Preprint KhPTI 89-48, 1989.
2. *Physics of plasma-wall interactions in controlled fusion /* Edited by D.E. Post and R. Behrisch. Plenum Publishing Corporation, 1986, p. 301.
3. D.P. Stotler, C.H. Skinner, R.V. Budny, A.T. Ramsey, D.N. Ruzic, and R.B. Turkot // *Phys. Plasmas*. 1996, p. 4084-4094.
4. E.D. Volkov, V.M. Zalkind, V.G. Konovalov, et al. *The behavior of light and heavy impurities in HF-plasma heating in torsatron Uragan-3*: Preprint KhPTI 89-11, 1989.
5. V.K. Pashnev, A.A. Petrushenya, E.L. Sorokovoy. Hydrogen recycling during the RF-plasma heating in torsatron U-3M // *Book of Abstracts ICPPCF*, Kharkiv, Ukraine, 2014, p. 29.

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К ВОПРОСУ ОБ ЭКРАНИРУЮЩИХ СВОЙСТВАХ ЗАСЕПАРАТРИСНОЙ ОБЛАСТИ ПЛАЗМЫ В УСТАНОВКЕ У-3М

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При проведении экспериментов на торсатроне У-3М при ВЧ-способе создания и нагрева плазмы наблюдалось неожиданное уменьшение (примерно двукратное) средней плотности удерживаемой плазмы при ступенчатом нарастании напряжения на ВЧ-антенне. Пытаясь установить причину этого явления, мы оценили экранирующую роль засепаратрисной области плазмы по результатам недавно проведенных измерений. Было установлено, что на границе удерживаемой плазмы ослабление потока составляет: 6 % для H_2, 1.4, 7, 6 % для C, Fe, Ti соответственно. Это значительно ниже степени ослабления (~70 %), полученной в работе [1] для потока атомов C при лазерной абляции графитовой мишени.

ДО ПИТАННЯ ПРО ЕКРАНУЮЧІ ВЛАСТИВОСТІ ЗАСЕПАРАТРИСНОЇ ОБЛАСТІ ПЛАЗМИ В УСТАНОВЦІ У-3М

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При проведенні експериментів на торсатроні У-3М при ВЧ-способі створення та нагріву плазми спостерігалося несподіване зменшення (приблизно двоpазове) середньої густини утримуваної плазми при ступінчастому наростанні напруги на ВЧ-антені. Намагаючись встановити причину цього явища, ми оцінили екрануючу роль засепаратрисної області плазми за результатами недавно проведених вимірювань. Було встановлено, що на межі утримуваної плазми ослаблення потоку становить: 6 % для H_2, 1,4, 7, 6 % для C, Fe, Ti відповідно. Це значно нижче ступеня ослаблення (~ 70 %), отриманого в роботі [1] для потоку атомів C при лазерній абляції графітової мішені.