https://doi.org/10.46813/2023-143-126

TIME BEHAVIOR OF THE H_α SPECTRAL LINE AND THE MOLECULAR HYDROGEN SPECTRAL LINE IN HYDROGEN PLASMA IN THE URAGAN-2M STELLARATOR

V.M. Bondarenko, R.O. Pavlichenko, M.V. Zamanov, Y.V. Kovtun, O.V. Lozin, M.M. Kozulia

Institute of Plasma Physics, National Science Center
"Kharkov Institute of Physics and Technology", Kharkiv, Ukraine
E-mail: bondarenkovn7ad@gmail.com

The studies of the scenario of hydrogen plasma creation with two sequential RF discharges during one pulse were carried out for the Uragan-2M stellarator. The first-stage discharge initiated the hydrogen pre-ionization at the generator anode voltage of 4 kV. The second-stage discharge was performed at the generator anode voltage selected from 6 to 9 kV. As result, plasma with an electron density up to $3.9\cdot10^{18}$ m^{-3} was produced in a confinement volume. An increase of voltage resulted in an earlier appearance of signals of electron density, the intensity of the H_α spectral line, and the intensity of the molecular hydrogen spectral line. The increase of the time-dependent intensities of these signals was also registered.

PACS: 52.55.Hc, 52.70.Kz

INTRODUCTION

A study of time evolution of the H_α spectral line and other hydrogen spectral lines emitted by plasma has a particular interest for the diagnostics of optical emission spectroscopy in experiments on the confinement and heating of plasma in the Uragan-2M (U-2M) stellarator at the ion cyclotron range of frequency (ICRF) [1].

The emission spectroscopy studies of the present experiments were focused on the measurement of the time-dependent intensities of spectral lines within U-2M. The H_α spectral line at $\lambda = 6562.8$ Å and the molecular hydrogen spectral line at $\lambda = 4631.8$ Å were studied. Both lines were registered together with the measurements of plasma electron density.

The spatial profiles of the H_α spectral line were also measured earlier in experiments on the Uragan-3M (U-3M) stellarator [2]. Recently, the time behavior of H_α in U-3M was analyzed in [3].

During one pulse of U-2M, one RF discharge pre-ionized hydrogen to the pre-ionization stage (PI stage). Other RF discharge created the plasma of the main plasma stage (MP stage) after a short time interval [3].

Evaluation of time delay between experimental signals, caused by the change of the RF generator anode voltage, is one of the important questions considered in this study.

In particular, the time delay of hydrogen plasma build-up was analyzed, depended on the discharge conditions in U-3M [4].

Similar experiment was recently performed at the U-2M [5]. The time delay was identified by a start of the H_α amplitude growth.

A similar idea is considered in this study. The time-dependent signals of the microwave interferometry and the optical spectroscopy were compared for two cases: 1) two signals of one type of diagnostics at the lowest and highest anode voltages, and 2) the intensity signal of one spectral line with the electron density signal at the selected anode voltage.

The three types of experimental signals are as follows: electron density, H_α line intensity, and molecular line intensity.

An objective of this study is to analyze the effect of an increase of the anode voltage of the RF generator in the MP stage on time shifts between experimental signals of three types.

1. EXPERIMENTAL CONDITIONS

An experiment was carried out to clarify the effect of the anode voltage of the RF generator "Kaskad-1" (K-1) on time shift of experiments signals. The pulses in the MP stage of dense plasma creation differed only in the generator K-1 anode voltage. Other parameters, such as the magnetic field, hydrogen pressure, the frequencies of the RF generators, and the anode voltage of the RF generator "Kaskad-2" (K-2) were not changed.

The confining magnetic field was produced by currents in the coils of the helical field I_h = 13980 A, the toroidal field I_t = 5020 A, and the correcting field I_c = 247 A. The toroidal magnetic field at the toroidal axis is B_0 = 0.359 T. The operational parameter of this regime was K_φ = 0.367. A pressure of the working gas hydrogen was p = $3.2\cdot10^{-3}$ Pa.

The first stage of each pulse was a PI stage in the interval of 1...10 ms. The RF generator K-2 was switched on only during this stage, at a constant anode voltage U_{K2} = 4 kV and a frequency of 5.44 MHz. This generator operated with a frame antenna (FA) [6] during the first discharge. The gas breakdown and the creation of pre-ionization plasmas of hydrogen appeared at a low electron density of up to $2.4\cdot10^{17}$ m^{-3}.

The pulse included also the MP stage in the interval of 14...22 ms. The RF generator K-1 was switched on only at this stage. The anode voltage U_{K1} was specified from a sequence of 6, 6.5, 7, 7.5, 8, 8.5, and 9 kV at a frequency of 5.1 MHz. This generator was connected to a three-half-turn antenna (THTA) [5]. Dense plasma was created and sustained in the MP stage. The electron density was significantly higher than in the PI stage.

The line-averaged electron density $\bar{n}_e(t)$ (average over the line of sight through the plasma) was measured by means of a 2 mm microwave superheterodyne interferometer. The horizontal line of sight of the interferometer crosses the vertically elongated plasma in the poloidal cross-section of the stellarator vacuum chamber [7], as shown in Fig. 1.

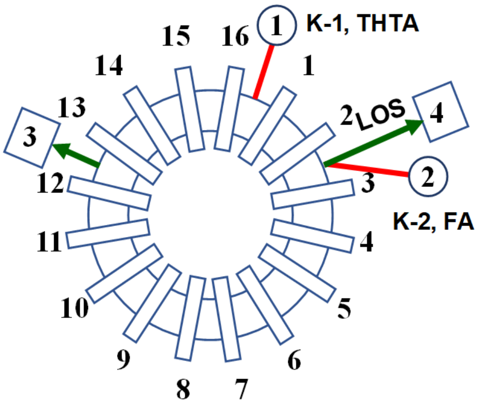

Fig. 1. A schematic top view of the Uragan-2M stellarator: 1 – a three-half-turn RF antenna; 2 – a frame RF antenna; 3 – microwave interferometry; 4 – optical spectroscopy. Toroidal coil numbers are № 1–16

The time-dependent intensities of two spectral lines were measured by means of the optical spectroscopy with a high temporal resolution. This data was compared with the average electron density.

A spectroscopic line of sight is located very close and parallel to the major radius of the stellarator. The line of sight crosses the horizontally elongated plasma and exits the optical port from the stellarator to an interference filter and a monochromator, as demonstrated in Fig. 1.

The intensity $I_\alpha(t)$ of the H_α spectral line with $\lambda = 6562.8$ Å was measured using the interference filter, transmitting only the H_α line. The monochromator MDR-23 was used to measure the intensity $I_{H2}(t)$ only of the molecular hydrogen spectral line with the $\lambda = 4631.8$ Å.

The H_α interference filter was of the narrow-band type with the maximal transmittance $T_{max} = 75$ % of the H_α spectral line. A wavelength resolution of the monochromator was sufficient to identify characteristic band structures.

The molecular hydrogen spectral line $\lambda = 4631.84$ Å relates to a singlet transition $1s\sigma 3d\sigma\ (G\ ^1\Sigma_g^+) \rightarrow 1s\sigma 2p\sigma\ (B\ ^1\Sigma_u^+)$ with decay $G_0 \rightarrow B_0$ from the vibrational level and decay R_4 from the rotational level [8, 9].

2. ANALYSIS OF EXPERIMENTAL RESULTS

The raw data obtained from the spectroscopy and microwave interferometry was smoothed for the experimental data analysis.

The smoothed time-dependent average electron densities $\bar{n}_e(t)$ with the anode voltage parameter U_{K1} and pulse numbers № 117–123 are presented in Fig. 2. An example of raw data at 9 kV is also shown.

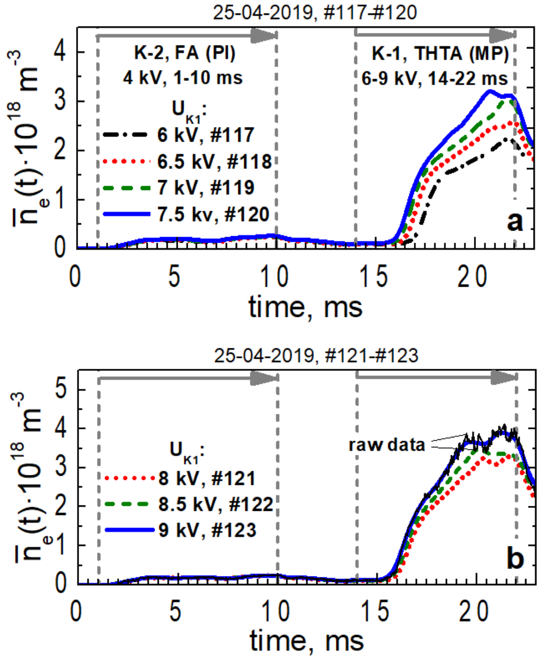

Fig. 2. The time-dependent average density $\bar{n}_e(t)$ with the anode voltage parameter U_{K1}: a – 6...7.5 kV and b – 8...9 kV

It is sufficient to select only integer voltage parameters of U_{K1} for adequate presentation of data.

The intensity $I_\alpha(t)$ of the H_α spectral line and the intensity $I_{H2}(t)$ of the molecular hydrogen spectral line are plotted respectively in Fig. 3 after a smoothing procedure.

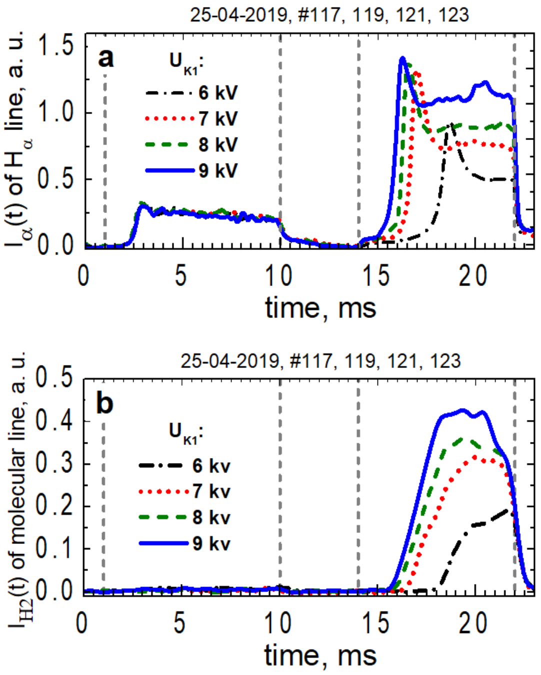

Fig. 3. The intensities: a – $I_\alpha(t)$ of the H_α line and b – $I_{H2}(t)$ of the molecular line with the anode voltage parameter U_{K1}

The anode voltage U_{K2} did not change in the PI stage with the parameter U_{K1} increase. As a result, the time-dependent density $\overline{n}_e(t)$ and intensities $I_\alpha(t)$, and $I_{H2}(t)$ of spectral lines changed insignificantly in the PI stage.

Four anode voltages used in experiments were denoted as $U_{K1,1}$ = 6 kV, $U_{K1,2}$ = 7 kV, $U_{K1,3}$ = 8 kV, and $U_{K1,4}$ = 9 kV, for optimization of notation.

The relative deviation in the PI stage, at anode voltages increasing from $U_{K1,1}$ to $U_{K1,4}$, is 5.1% of density signals and 5.7% of H_α signals, excluding the molecular line of a very low intensity.

The relative deviation was calculated at each time point among signals of one type. Then the deviations for signal of each type were averaged over the PI stage to find two relative deviations shown above.

The analysis of each time-dependent experimental signal $\overline{n}_e(t)$, $I_\alpha(t)$, and $I_{H2}(t)$ must be carried out in a time interval of initial amplitude growth. The signal grows from the time point of a zero amplitude to the time point of the maximal amplitude. Each signal gradually moves to the start of the MP stage and increases in amplitude with the increase of anode voltage from $U_{K1,1}$ to $U_{K1,4}$.

The maximal electron density $\overline{n}_e(t)$ in the MP stage at the anode voltage $U_{K1,1}$ is $2.2\cdot10^{18}$ m^{-3}, as shown in Fig. 2,a. It takes a maximum value of $3.9\cdot10^{18}$ m^{-3}, as Fig. 2,b shows, at the anode voltage of $U_{K1,4}$. This is the highest density among the anode voltages from $U_{K1,1}$ to $U_{K1,4}$.

Existing time shifts of each studied time dependence can be more clearly demonstrated, using three time points t_A, t_B, and t_C corresponding to 10, 50, and 100%, respectively, of the maximum amplitude in the initial interval of the amplitude growth.

Two programs are described below, presenting the technique for calculation of time points and time shifts of points A, B, and C of experimental signals.

2.1. TIME SHIFTS OF SIGNALS OF ONE TYPE

This subsection presents a program for calculating the time shifts Δt of the points A, B, and C, found for each experimental signal separately from others. The shifts correspond to an increase of the anode voltage U_{K1} from $U_{K1,1}$ to $U_{K1,4}$.

The program finds the time points $t_{A,n,6}$, $t_{B,n,6}$, and $t_{C,n,6}$ of electron density signals at the anode voltage $U_{K1,1}$. The first subscript in an expression is the point name, the second is the electron density denoted here as *n*, and the third is the anode voltage. The time points $t_{A,n,9}$, $t_{B,n,9}$, and $t_{C,n,9}$ are found at the anode voltage $U_{K1,4}$.

The differences $t_{A,n,9} - t_{A,n,6}$, $t_{B,n,9} - t_{B,n,6}$, and $t_{C,n,9} - t_{C,n,6}$ are equal to the time shifts $\Delta t_{A,n,(6,9)}$, $\Delta t_{B,n,(6,9)}$, and $\Delta t_{C,n,(6,9)}$, respectively, resulted from the increase of anode voltage, indicated by the third subscript (6,9). The time shifts are shown in the first column of Table 1.

The time shifts $\Delta t_{A,\alpha,(6,9)}$, $\Delta t_{B,\alpha,(6,9)}$, and $\Delta t_{C,\alpha,(6,9)}$ of the H_α line intensity signals are used with the second subscript α and are shown in the second column of Table 1.

The time shifts $\Delta t_{A,m,(6,9)}$, $\Delta t_{B,m,(6,9)}$, and $\Delta t_{C,m,(6,9)}$ of the molecular line intensity signals were also found. They are used with the second subscript *m* and are shown in the third column of Table 1.

Table 1

Time shifts of points A, B, and C for three signal types as a result of an increase of the anode voltage from $U_{K1,1}$ to $U_{K1,4}$

Points	Time shift Δt of point, ms		
	electron density	H_α line	molecular line
A	1.1	2.0	2.2
B	0.7	2.4	1.9
C	0.4	2.4	2.4

2.2. TIME SHIFTS OF LINE INTENSITY SIGNALS RELATIVE TO ELECTRON DENSITY SIGNALS

This subsection demonstrates the effect of the increase of the anode voltage $U_{K1,1}$, $U_{K1,2}$, $U_{K1,3}$, and $U_{K1,4}$ on the time shifts of points A, B, and C of H_α intensity signals or molecular line intensity signals relative to the corresponding points of electron density signals.

The program finds the time points of electron density signals at the anode voltage of $U_{K1,1}$, $U_{K1,2}$, $U_{K1,3}$, and $U_{K1,4}$ respectively: 1) $t_{A,n,6}$, $t_{B,n,6}$, $t_{C,n,6}$, 2) $t_{A,n,7}$, $t_{B,n,7}$, $t_{C,n,7}$, 3) $t_{A,n,8}$, $t_{B,n,8}$, $t_{C,n,8}$, and 4) $t_{A,n,9}$, $t_{B,n,9}$, $t_{C,n,9}$. The third subscript denotes the anode voltage.

These four groups of expressions for time points can be represented as short expressions $t_{A,n,u}$, $t_{B,n,u}$, and $t_{C,n,u}$, where the variable u = $U_{K1,1}$, $U_{K1,2}$, $U_{K1,3}$, and $U_{K1,4}$ denotes the sequence of anode voltages introduced into the expression instead of the last constant subscript.

The program then calculates the time points of H_α intensity signals at specified anode voltages. The short expressions are: $t_{A,\alpha,u}$, $t_{B,\alpha,u}$, and $t_{C,\alpha,u}$. The second subscript here is α.

The differences given as the short expressions $t_{A,\alpha,u} - t_{A,n,u}$ are equal to the time shifts, also given as the short expressions $\Delta t_{A,\alpha\text{-}n,u}$. The shifts of points A of H_α signals were identified relative to points A of electron density signals. The second subscript expresses the two types of signals compared. The time shifts of points B and C, expressed respectively as $\Delta t_{B,\alpha\text{-}n,u}$ and $\Delta t_{C,\alpha\text{-}n,u}$ are calculated in a similar way.

The calculated time shifts of points A, B, and C are included in the first four columns of Table 2, following the notation of subscripts in the expressions of shifts.

Table 2

Time shifts of points A, B, and C at indicated anode voltages for: H_α intensity signals compared to electron density signals, molecular line intensity signals compared to electron density signals

Points	Anode voltage U_{K1}, kV							
	6	7	8	9	6	7	8	9
	$\Delta t_{\alpha\text{-}n,u}$, ms				$\Delta t_{m\text{-}n,u}$, ms			
A	0.3	-0.2	-0.3	-0.6	1.3	0.4	0.1	0.2
B	0.5	-0.7	-1.0	-1.2	1.1	0.3	0.1	0.0
C	-3.0	-4.6	-5.1	-5.0	0.0	-1.7	-2.2	-1.9

The program then calculates the time shifts of points A, B, and C of molecular line intensity signals relative to the corresponding points of electron density signals at specified anode voltages. The second subscript is *m*.

The short expressions of shifts are: $\Delta t_{A,m\text{-}n,u}$, $\Delta t_{B,m\text{-}n,u}$, and $\Delta t_{C,m\text{-}n,u}$. As in the case of H_α, the variable $u = U_{K1,1}$, $U_{K1,2}$, $U_{K1,3}$, and $U_{K1,4}$ denotes anode voltages. The calculated time shifts are shown in the last four columns of Table 2.

The time shift values are given below in the text without a minus sign, using the words "delay", "later", "ahead of", "earlier" and others.

2.3. COMPARISON OF TIME SHIFTS OF POINTS A, B, AND C

For clarity, the graphs of signals are plotted using only the points A, B, and C based on Figs. 2 and 3.

An increase of voltage of $U_{K1,1}$, $U_{K1,2}$, $U_{K1,3}$, and $U_{K1,4}$ results in a gradual shift of all points of all experimental signals to the start of the MP stage, in other words, to the start of the RF pulse of the generator K-1 operating with the THTA.

The points of the electron density $\overline{n}_e(t)$ at each anode voltage U_{K1} are presented in Fig. 4.

The time shifts taken from Table 1 are $\Delta t_{A,n,(6,9)} =$ 1.1 ms, $\Delta t_{B,n,(6,9)}$ = 0.7 ms, and $\Delta t_{C,n,(6,9)}$ = 0.4 ms. These shifts of electron density points are minimal among experimental signals of all types in the entire sequence of voltages.

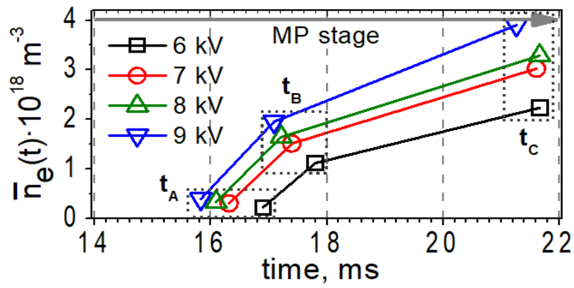

Fig. 4. The electron density $\overline{n}_e(t)$ at specified anode voltages, at time points t_A, t_B, and t_C. Each rectangle outlines a group of points corresponding to the time point subscript A, B, and C

The points A, B, and C of intensity I_α of the H_α line are shown in Fig. 5.

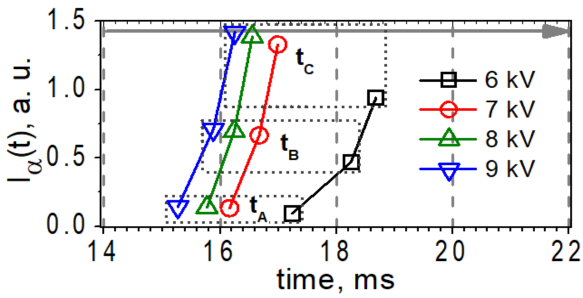

Fig. 5. The intensity $I_\alpha(t)$ of the H_α line at specified anode voltages, at three time points

The increase of voltage from $U_{K1,1}$ to $U_{K1,4}$ in the entire sequence of voltages moves the intensity I_α points to the start of the MP stage with shifts $\Delta t_{A,\alpha,(6,9)}$ = 2.0 ms, $\Delta t_{B,\alpha,(6,9)}$ = 2.4 ms, and $\Delta t_{C,\alpha,(6,9)}$ = 2.4 ms. These shifts are much more significant than the shifts $\Delta t_{A,n,(6,9)}$, $\Delta t_{B,n,(6,9)}$, and $\Delta t_{C,n,(6,9)}$ of corresponding points of the electron density.

Table 2 shows that the points $t_{A,\alpha,6}$ and $t_{B,\alpha,6}$ of the H_α line intensity at the voltage of $U_{K1,1}$ appear somewhat later, with shifts $\Delta t_{A,\alpha\text{-}n,6}$ = 0.3 ms and $\Delta t_{B,\alpha\text{-}n,6}$ = 0.5 ms, than the corresponding points $t_{A,n,6}$ and $t_{B,n,6}$ of the electron density. But the intensity point $t_{C,\alpha,6}$ at $U_{K1,1}$ is found significantly earlier than the density point $t_{C,n,6}$, with a shift $\Delta t_{C,\alpha\text{-}n,6}$ = 3.0 ms.

The points $t_{A,\alpha,u}$ and $t_{B,\alpha,u}$ at anode voltages $u = U_{K1,2}$, $U_{K1,3}$, and $U_{K1,4}$ are ahead of the density points $t_{A,n,u}$ and $t_{B,n,u}$ with shifts $\Delta t_{A,\alpha\text{-}n,u}$ = 0.2; 0.3, and 0.6 ms, and $\Delta t_{B,\alpha\text{-}n,u}$ = 0.7; 1.0, and 1.2 ms. The points $t_{C,\alpha,u}$ at given voltages u appear noticeably earlier than the density points $t_{C,n,u}$ by $\Delta t_{C,\alpha\text{-}n,u}$ = 4.6; 5.1, and 5.0 ms.

The time points of the molecular line intensity I_{H2} are shown in Fig. 6.

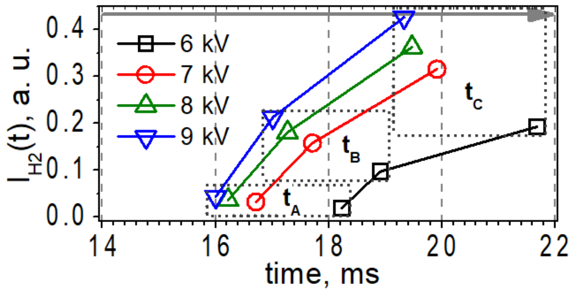

Fig. 6. The intensity $I_{H2}(t)$ of the molecular hydrogen line (λ = 4631.8 Å) at specified anode voltages, at three time points

The shifts of the time points of the molecular line intensity I_{H2} to the start of the MP stage in the entire voltage sequence are $\Delta t_{A,m,(6,9)}$ = 2.2 ms, $\Delta t_{B,m,(6,9)}$ = 1.9 ms, and $\Delta t_{C,m,(6,9)}$ = 2.4 ms, as Table 1 shows. These shifts are comparable to the shifts of the H_α line intensity points.

As seen from Table 2, at anode voltages $u = U_{K1,1}$, $U_{K1,2}$, $U_{K1,3}$, and $U_{K1,4}$, the time points $t_{A,m,u}$ and $t_{B,m,u}$ of the molecular line intensity are delayed after the corresponding density time points $t_{A,n,u}$ and $t_{B,n,u}$.

The calculated shifts are $\Delta t_{A,m\text{-}n,u}$ = 1.3; 0.4; 0.1, and 0.2 ms, and $\Delta t_{B,m\text{-}n,u}$ = 1.1; 0.3; 0.1 ms, and zero shift. It means that the intensity time point $t_{B,m,9}$ and the density time point $t_{B,n,9}$ coincide. These delays decrease as the anode voltage increases.

The shift $\Delta t_{C,m\text{-}n,6}$ of the time point of the molecular line intensity $t_{C,m,6}$ at the voltage $U_{K1,1}$ is equal to zero, since this time point and the corresponding density time point $t_{C,n,6}$ coincide. Time points $t_{C,m,u}$ at anode voltages $u = U_{K1,2}$, $U_{K1,3}$, and $U_{K1,4}$ appear ahead of the corresponding density time points $t_{C,n,u}$ with three time shifts $\Delta t_{C,m\text{-}n,u}$ = 1.7; 2.2, and 1.9 ms. The shift has a tendency to increase with increasing voltage.

Below we briefly summarize the obtained results, concerning time points and time shifts. The time point shifts among one-type signals were found in Subsection 2.1. The type of signals that appeared earlier than others was determined after the analysis of time shifts. Subsection 2.2 shows the time shifts among signals of different types as the anode voltage increases. The time points were characterized in terms of "delay" or "ahead of" relative to other time points. This can be useful in numerical simulations. Subsection 2.3 shows the time points on the graphs. Time shifts were compared in different cases.

In prospect, experiments with RF discharge plasma on the Uragan-2M stellarator will lead to the creation of a database of experimental data for numerical simulation. The temporal waveforms of the H_α spectral line and the molecular hydrogen spectral line at $\lambda = 4631.8$ Å can be modeled, using a system of differential equations [10], similar to that used for the Uragan-3M stellarator [3].

CONCLUSIONS

A technique for processing the time-dependent experimental signals of hydrogen plasma in the Uragan-2M stellarator has been developed. The three types of signals were analyzed: the electron density, intensities of H_α spectral line, and molecular hydrogen line.

The scenario of plasma creation in U-2M included two sequential RF discharges. Only the second RF discharge was analyzed comprehensively. The studies of plasma parameters were carried on depending only on the anode voltage of the generator K-1.

It has been found that an increase of the anode voltage moves signals of all three types to the start of the RF discharge.

The technique includes two programs. They are used to select points of one type (e. g. signal maximums), the signal type (e. g. H_α or other signals) and the anode voltage to process time shifts between the points.

The signal time shifts of one of three selected types were found using this technique at the maximal and minimal anode voltage of the RF generator. It was shown that the shifts of signals of both spectral lines are larger than the shifts of electron density signals.

This technique was applied to different type signals at one of four selected voltages. It was found the time shifts of H_α or molecular line signals relative to the electron density signals. The H_α signals are generally ahead of the electron density signals. The signals of molecular line are generally delayed relative to the electron density signals.

The obtained results can be used at numerical simulation of temporal waveform changes of the H_α spectral line and the molecular hydrogen spectral line in hydrogen plasma of fusion devices.

REFERENCES

1. V.E. Moiseenko et al. First experiments on ICRF discharge generation by a W7-X-like antenna in the Uragan-2M stellarator // *J. Plasma Phys*. 2020, v. 86, p. 905860517.
2. V.N. Bondarenko, V.G. Konovalov, S.A. Tsybenko, et al. Investigation of radial distributions of spectral line radiation emissivities in torsatron URAGAN-3M // *Problems of Atomic Science and Technology. Series "Plasma Physics" (83)*. 2003, № 1, p. 23-26.
3. V.N. Bondarenko, A.A. Petrushenya. Modeling of time behavior of H, H_2 neutral densities, and H_α line intensity in the RF plasma of the Uragan-3M torsatron // *Problems of Atomic Science and Technology. Series "Plasma Physics" (119)*. 2019, № 1, p. 13-16.
4. V.E. Moiseenko, A. Lyssoivan, T. Wauters, et al. Radio-frequency plasma start-up at Uragan-3M stellarator // *Problems of Atomic Science and Technology. Series "Plasma Physics" (107)*. 2017, № 1, p. 54-59.
5. V.E. Moiseenko, A.V. Lozin, M.M. Kozulia, et al. Three-half-turn antennas start-up // *Problems of Atomic Science and Technology. Series "Plasma Physics" (119)*. 2019, № 1, p. 263-266.
6. V.E. Moiseenko, V.L. Berezhnyj, V.N. Bondarenko et al. RF plasma production and heating below ion-cyclotron frequencies in Uragan torsatrons // *Nucl. Fusion*. 2011, v. 51, p. 083036.
7. R.O. Pavlichenko, N.V. Zamanov, A.E. Kulaga, and Uragan-2M team. A high speed 140 GHz microwave interferometer for density fluctuation measurements in Uragan-2M stellarator // *Problems of Atomic Science and Technology. Series "Plasma Physics" (118)*. 2018, № 6, p. 332-335.
8. G.H. Dieke. *The Hydrogen Molecule Wavelength Tables of Gerhard Heinrich Dieke* / Ed.: H.M. Crosswhite. New York: "Wiley", 1972, 1616 p.
9. T.G. Moran. Spectroscopic study of molecular-hydrogen processes in a mirror-confined plasma // *Phys. Rev. E*. 1995, v. 51(4), p. 3464-3474.
10. S.J. Fielding et al. Recycling in gettered and diverted discharges in DITE tokamak // *J. Nucl. Mater*. 1978, v. 76, 77, p. 273-278.

Article received 19.02.2022

ЧАСОВА ПОВЕДІНКА СПЕКТРАЛЬНОЇ ЛІНІЇ H_α ТА СПЕКТРАЛЬНОЇ ЛІНІЇ МОЛЕКУЛЯРНОГО ВОДНЮ У ВОДНЕВІЙ ПЛАЗМІ В СТЕЛАРАТОРІ УРАГАН-2М

В.М. Бондаренко, Р.О. Павліченко, М.В. Заманов, Ю.В. Ковтун, О.В. Лозін, М.М. Козуля

Для стеларатора Ураган-2М проведено дослідження сценарію створення водневої плазми з двома послідовними ВЧ-розрядами протягом одного імпульсу. Розряд першого ступеня ініціював попередню іонізацію водню при анодній напрузі генератора 4 кВ. Розряд другого ступеня проводився при анодній напрузі генератора, обраній від 6 до 9 кВ. В результаті в об'ємі утримання утворювалася плазма з електронною густиною до $3{,}9 \cdot 10^{18}$ м$^{-3}$. Підвищення напруги призводило до більш ранньої появи сигналів електронної густини, інтенсивності спектральної лінії H_α та інтенсивності спектральної лінії молекулярного водню. Також зареєстровано збільшення залежних від часу інтенсивностей цих сигналів.