SOME ASPECTS OF RF DISCHARGE IN THE "U-3M" TORSATRON

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Studies were made into the behavior of frequencies and harmonic power of the RF field used for plasma production and heating in the "U-3M" torsatron.
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Most of theoretical and experimental investigations on RF heating of plasma in the U-3M torsatron have been aimed at perfecting both the methods of excitation of required waves in the plasma, and the mechanisms of transfer of wave energy to ions and electrons [1]. However, these processes are essentially dependent on the quality of parameters of the initial RF pump wave. Moreover, this very wave is used in the U-3M for plasma production. In our previous work [2], the spectra of reflectometer signals have exhibited separate peaks at the frequencies being multiples of harmonics. It has been demonstrated that the frequencies are the harmonics of the RF pump field used in the U-3M for plasma production and heating.

The present paper is concerned with the dynamics of frequencies and powers of the first three harmonics of the RF pump field in the process of the discharge. (The experimental conditions and the signals of the diagnostics used have been described in [2]).

A high coherence of signals from two reflectometer channels at the harmonic frequencies (Fig. 1a) points to their common nature. A high spatial coherence at harmonic frequencies holds over the course of the whole RF discharge. The coherence signals at the initial stage of discharge (5 to 6 ms) broaden in frequency (Fig. 1b). The time coherence of harmonics from one reflectometer channel is substantially violated in the time windows (4 to 5 ms) and (30 to 31 ms) (see Fig. 1c). This may be indicative of the variations in the RF field frequencies during the discharge at both the fundamental frequency and its harmonics.

To verify this assumption, the power spectral density (PSD) was calculated in each time window of 1 ms duration over the whole RF pulse (50 ms). The frequency values of three fundamental harmonics from each spectrum were calculated by the technique described in ref. [2]. The final data on the dynamics of harmonic frequencies in the process of the discharge in the U-3M are presented in Fig. 2. As is seen from the plots, the harmonic frequencies at the stage of plasma initiation (4-8 ms) remain practically unchanged. With the occurrence of breakdown (8 ms) the frequency amplitudes abruptly increase up to their maximum values (11th ms) and then start to fall off, first, up to the 15th ms, quickly, and after the 15th ms - very slowly. The time variation of harmonic frequencies during the discharge is very much similar to the behavior of plasma density up to the moment of RF pulse cessation (see Fig. 2c) [2]. A special point in the plot of the first harmonic marks the frequency f_1 = 8768 kHz. This frequency value has been measured by the independent standard method using a frequency meter. The value is close to the average frequency value of the first harmonic during the discharge. The plots for the second and third harmonics were obtained from the experiments rather than by simple doubling and trebling of the fundamental frequency. Quite identical qualitative and quantitative variations in the frequencies of the first three harmonics during the discharge were obtained from the other diagnostic channel [2].

From the PSD set, for each millisecond of the RF pulse duration the power was also calculated at each of the three harmonics. The results obtained from the reflectometer 2 channel (Fig. 1 in [2]) are presented in Fig. 3. With the onset of the RF pulse at the 4th ms, the power of the first harmonic increases very quickly. Before reaching its maximum value the rate of power increase somewhat decreases. At the sixth millisecond, the power reaches its maximum and then (8th ms) likewise quickly falls off. Approximately from this time forth, the power remains practically unchanged throughout the RF pulse, showing only small fluctuations. This behavior of the first-harmonic RF field power is in qualitative agreement with the classical description of the process of RF discharge initiation [3]. Between the 4th and 6th milliseconds, close to the antenna, there occurs an avalanche ionization of gas due to the electric field of the antenna-radiated RF wave. At the peak value of power (6th ms) the gas breakdown throughout the torus occurs, and by the 8th ms a toroidal plasma bunch is eventually formed. The time duration of discharge initiation is in good agreement with the results of ref. [4], where optimum conditions of the starting phase of the RF discharge in the U-3M were studied in relation to the working gas pressure and the RF voltage applied to the antenna. It is seen from Fig. 3 that the phase of discharge initiation can be clearly traced at the second and third harmonics, too. However, their power contribution to the plasma is substantially lower. The ratios of the maximum harmonic power at the stage of gas breakdown to the average harmonic power at the quasi-stationary stage of the discharge are 300/15, 47/25 and 8/5 for the first, second and third harmonics, respectively. Much the same variation in harmonic powers during the discharge is observed in the first channel of the reflectometer (below the plasma core) (Fig. 4). The ratios of the maximum harmonic power at the stage of gas breakdown to the average harmonic power at the quasi-stationary stage of the discharge have changed to be 165/50, 75/75 and 1/10 for the first, second and third harmonics, respectively.

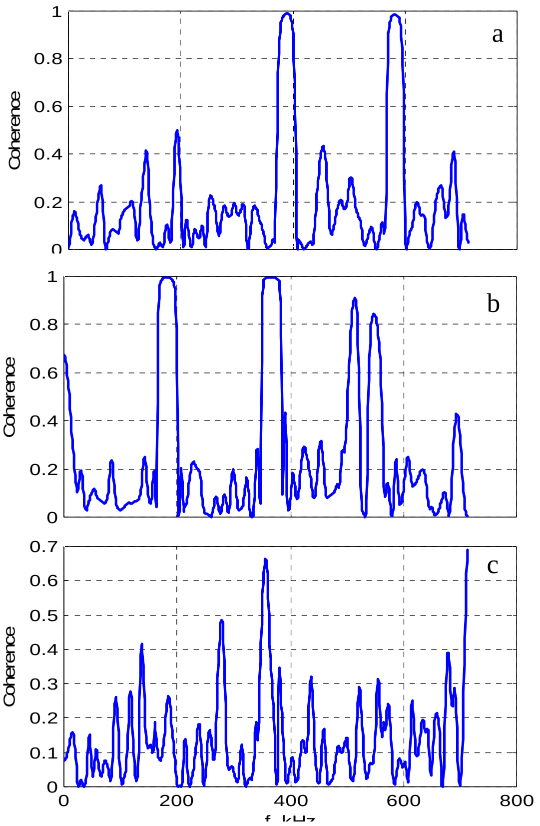

Fig. 1. Coherence at harmonic frequencies: a) k1, k2, t=30-31 ms; b) k1, k2, t=5-6 ms; c) k2, t_1=4-5 ms, t_2=30-31ms

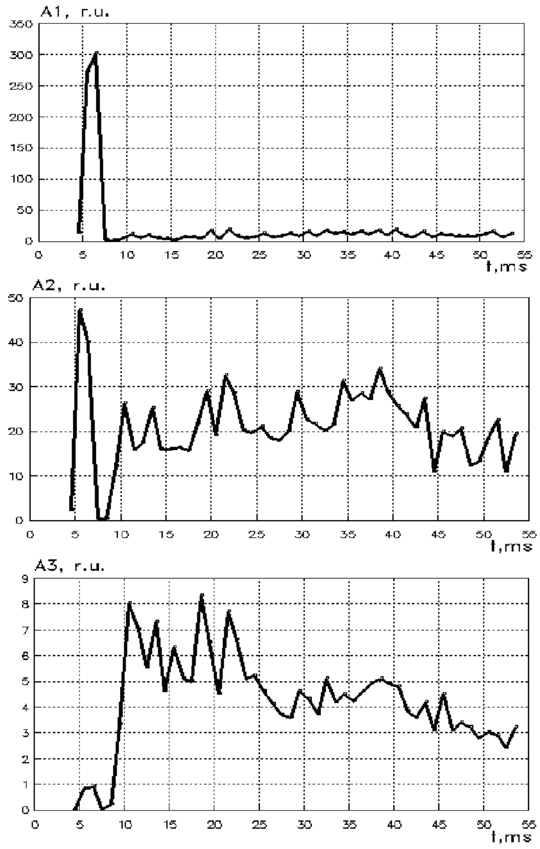

Fig. 3. Behavior of RF field harmonic amplitudes during the discharge (channel 2)

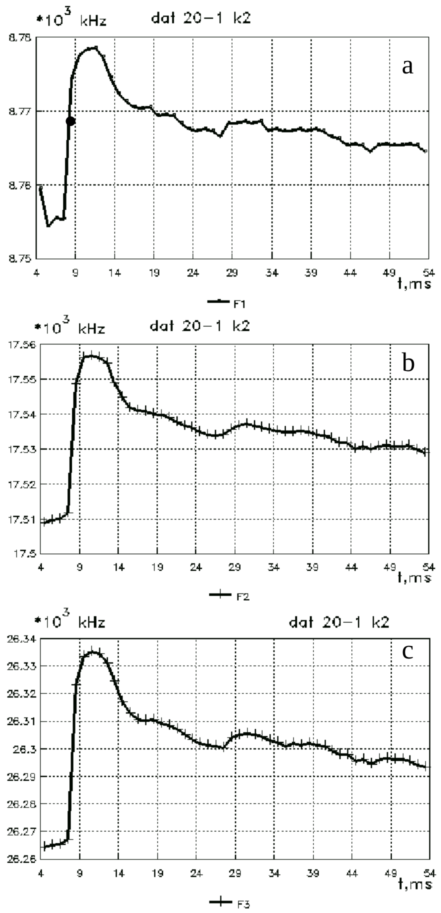

Fig.2. Behavior of RF field harmonic frequencies during the discharge

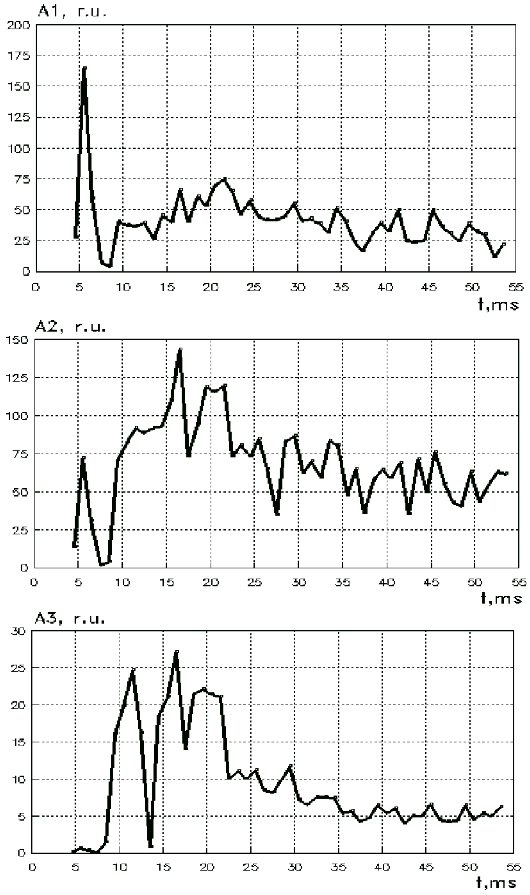

Fig. 4. Behavior of RF field harmonic amplitudes during the discharge (channel 1)

The differences in the RF field power redistribution between the harmonics with the evolution of the discharge for the upper and lower half-planes are shown in Fig. 5. Thus, the first harmonic power below the plasma core decreases, while the second and third harmonic powers increase. The harmonic power asymmetry relative to the equatorial plane persists from discharge to discharge. However, the cause of the asymmetry has not been established.

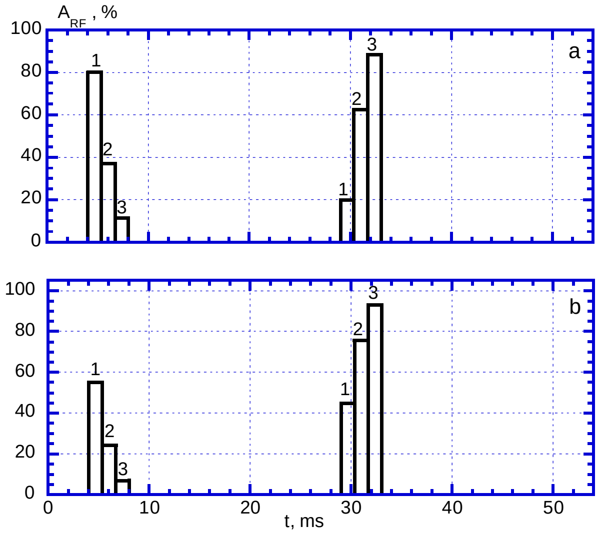

Fig. 5. Distribution of averaged harmonic amplitudes between the breakdown stages (4 to 9 ms) and the quasi-stationary stage of the discharge (9 to 54 ms): a) upper half-plane; b) lower half-plane

In conclusion it can be noted the following.

The behavior of frequencies and powers of the first three harmonics of the RF field used for plasma production and heating in the “U-3M” torsatron has been determined. At the stage of gas breakdown the harmonic power increases from the third harmonic to the first one, and at the quasi-stationary stage it grows from the first harmonic to the third one. Most of the first harmonic power is spent for gas breakdown. This points to the necessity of using the other method of preliminary gas ionization in order to increase the efficiency of RF plasma heating.

The present studies have uncovered the asymmetry in the contribution of RF pulse power to the harmonics from the external and inner sides of the plasma column, and particularly, in relation to the equatorial plane.

The generation of the second harmonic of the RF field may stimulate the occurrence of the radial electric-field component [5]. The presence of the radial electric field in the U-3M is evidenced by a poloidal rotation of plasma in crossed fields ExB [6]. The formation of regions with a high shear of the radial electric field in the vicinity of rational surfaces is one of the prerequisites of internal transport barrier formation [7].

The available conditions for spatial asymmetry of harmonic powers and for substantial increase in the powers of the second and third harmonics need further study, since these phenomena may have an effect on the efficiency of the RF discharge in the U-3M.

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НЕКОТОРЫЕ АСПЕКТЫ ВЧ-РАЗРЯДА В ТОРСАТРОНЕ "У-3М"

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Определена динамика изменения частот и мощности гармоник ВЧ-поля, используемого для создания и нагрева плазмы в торсатроне "У-3М".

ДЕЯКІ АСПЕКТИ ВЧ-РОЗРЯДА В ТОРСАТРОНІ "У-3М"

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Визначена динаміка зміни частот і потужності гармонік ВЧ-поля, яке використовується для створення і нагрівання плазми в торсатроні "У-3М".