PECULIARITIES OF PLASMA FLUCTUATIONS DURING RF HEATING IN URAGAN-3M TORSATRON BY MEANS OF TWO ALFVEN WAVES

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Three wave interaction has been observed in experiments on Uragan-3M torsatron. Two RF antennas with frequencies Ω_1 and Ω_2 were used simultaneously for plasma production and heating. Plasma was probed by microwaves, these allowed to study reflection of microwaves at almost whole plasma radius. Spectral analysis of reflected microwaves showed an existence of plasma density fluctuation with frequency $\Omega_1 - \Omega_2$. The suppression of plasma low frequencies was observed, when the plasma oscillation with $\Omega_1 - \Omega_2$ frequency has appeared. Microwaves probing of these fluctuations is the useful tool for studies of their influence on plasma behavior and possibly RF power absorption profile.
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It is known [1] that perturbations induced in plasma by powerful electromagnetic (EM) wave influence the propagation of other waves propagating through perturbed region. Plasma parameters – electroconductivity and dielectric permittivity – are being modulated by a powerful wave with frequency of Ω_1. If other powerful EM wave with frequency of Ω_2 propagates through the same region, plasma parameter modulation on a difference frequency $\Omega = \Omega_1 - \Omega_2$ is due to nonlinear interaction. If the third EM wave propagates (reflects) through this region, it can be modulated due to modulation of plasma parameters on frequency Ω. Interaction of waves in plasma was studied in 3-wave approximation for arbitrary number of interacting waves [2]. The difference frequency perturbations have been observed at interaction of SHF waves in the upper hybrid resonance region [3].

In this work we have studied plasma fluctuations induced in Uragan-3M (U3-M) torsatron difference frequency of two RF oscillators used for plasma production and heating by absorption of waves in region of Alfven resonance [4]. Two RF antennas – frame type and 3-half turn type [4] were fed from separate oscillators (frequency – $\Omega_{1,2} \approx 8.4 \ldots 8.8$ MHz, RF power – up to 200kW, pulse duration – up to 50 ms); different scenarios of antenna turn on/off were used including of 20 ms overlapping of RF pulses. The difference of oscillator frequencies was varied for optimization of power absorption ($\Delta\Omega \approx 0.1 \ldots 0.4$ MHz).

In these experiments data on plasma density and it fluctuations were obtained by means of 3 channel microwave reflectometer, edge H_α line observation and ECE (2nd harmonic, X-mode). Schematic setup of RF and microwave antennas is shown on Fig.1.Plasma was probed by microwave in 3 locations and for different directions: in horizontal direction – X-wave probing F = 18…26 GHz (Fig.1b) - both inside (1) and outside (2) and in vertical direction (3) – O-wave probing F =10Hz. This allowed to study reflection of microwaves at almost whole plasma radius (0.1 < r/a < 0.9) [5].

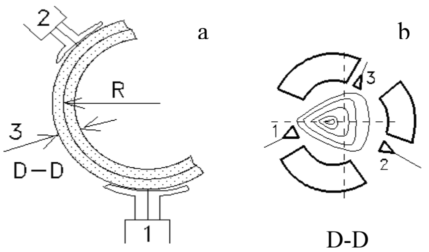

Fig.1

Line averaged electron density was measured by 2mm microwave interferometer.

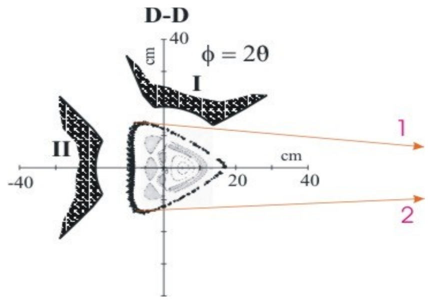

Fig.2

For H_α-emission observation we have used a simple setup: 2 lens + filters + PMT. These detectors could get plasma light from volumes of ~ 2 cm cross-beam size (Fig.2). ECE signals were received in range F=30…37.5 GHz.

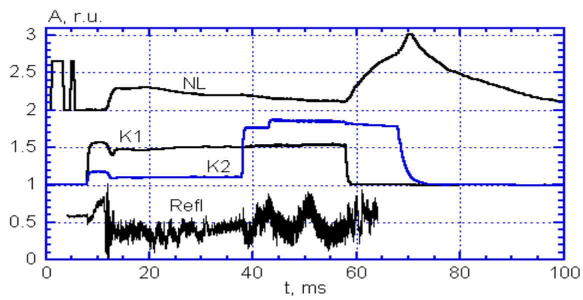

Fig.3. Time dependency integral density NL, HF curent of 1st (K1) and 2nd (K2) oscillators, reflected UHF signal

Data were sampled with ADC (sampling frequency – up to 3 MHz), stored and analyzed.

Spectral analysis of reflected microwaves and H_α-emission showed that a strong component of high frequency fluctuations (F = 70 … 300 kHz) has been observed on spectra of signals related to electron density fluctuations (Fig.4.) during time period of simultaneous operation of both K1, K2 oscillators (Fig.3).

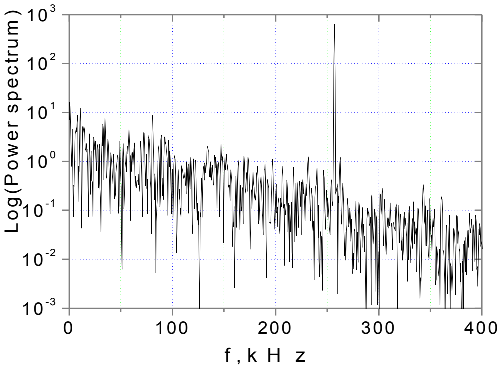

Fig.4. Spectrum of reflected X-wave (F=25 GHz) during time period of simultaneous operation of two RF oscillators

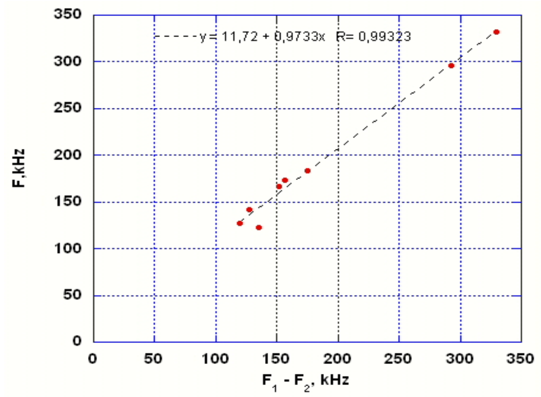

Fig.5. Dependency of excited oscillation on frequency difference of oscillators

As for as it was seen that the frequency and amplitude of this component depended on RF oscillators frequency a close look on relationship between RF oscillators frequencies and frequency of fluctuations was done.

Results of these observations summarize Fig.5 showing that strong electron density modulation on the difference (beat) frequency F ≈ $F_1 - F_2$ (F_1, F_2 – RF oscillator frequencies) takes place.

It was interesting to study properties of these fluctuations, in particular – radial distribution and RF power dependence.

For comparison of data obtained for different discharges and for different probing microwave frequencies a normalization of data of numerical spectral analysis was performed according to formula (1)

$$P_{norm}(f_1 - f_2) = (\langle P_{peak}\rangle \langle A_{level}\rangle)/\langle P_{full}\rangle \quad (1)$$

where $\langle P_{full}\rangle = \frac{1}{n_i}\sum P_i(f)$ – averaged spectral power in the frequency range of 5ч500 kHz, $\langle P_{peak}\rangle = \frac{1}{n_k}\sum P_k(f)$ – averaged spectral power in the frequency range of 4kHz around the beat frequency, $\langle A_{level}\rangle = \frac{1}{n_i}\sum A_i$ – signal amplitude averaged by data ensemble.

Time behavior of reflected microwave fluctuation spectra in discharges with 10 ms overlapping of RF oscillator pulses is shown on Fig.6.

Two frequency domains are observed: broad band (few kHz – ≈ 100 kHz) "natural" fluctuations and RF induced beat frequency region ($\Omega \approx \Omega_1 - \Omega_2$).

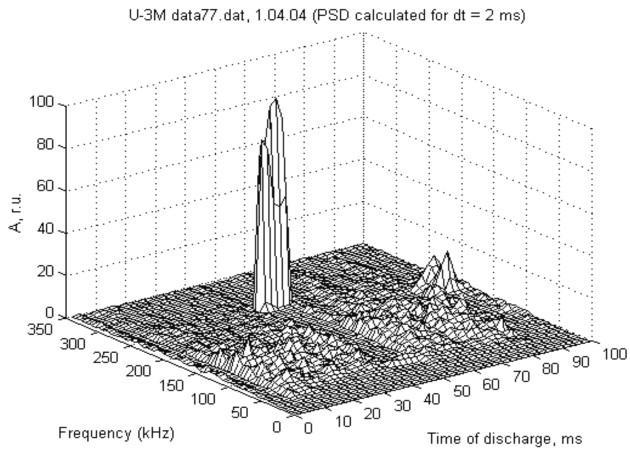

Fig.6. Temporal-frequency behavior of reflected wave fluctuations

Intensity of beat frequency fluctuations is much larger then that of "natural" broadband fluctuations. Their appearance is accompanied by suppression of "natural" fluctuations. After turn off of first RF oscillator, "natural" fluctuations are restored. The effect of suppression of the "natural" fluctuations is stronger with increase of beat frequency fluctuations.

Low level oscillations in the beat frequency range were observed also when the 2nd RF oscillator was not powered. This can be explained as result of excitation of the 2nd oscillator by the oscillations of the 1st one.

Fluctuations in the beat frequency range have a finite width of Δf = 5÷50 kHz and shape of this band is changing during overlap period: low frequencies prevail at the beginning, high frequencies – in the end of overlap period.

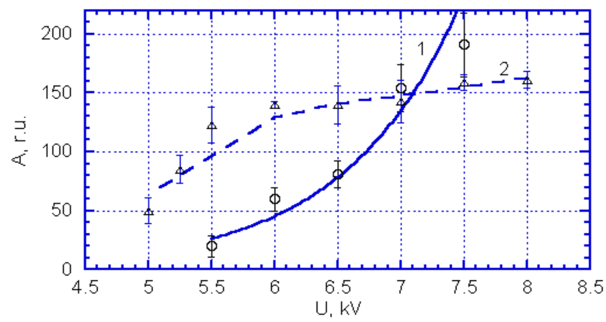

Fig.7. The reflected wave fluctuation amplitude versus the generator lamp voltage

The beat frequency fluctuation intensity depends on RF oscillator's power. This fact illustrates Fig7, where 1 – 2nd RF oscillator lamp anode voltage was constant (9 kV), 1st one was changed; 2 – 1st RF oscillator lamp anode voltage was constant (7.5 kV), 2nd one was changed.

It was interesting to study a radial distribution of the beat frequency fluctuations as for as it give some information of RF wave power radial distribution. This study was done with microwaves reflecting all along plasma radius (X-wave, 19÷25 GHz). The dependence of the beat frequency fluctuation obtained at probing frequency change is shown on Fig8. The reflecting layer position for a given probing frequency was determined from measured reflected wave phase shift

$$\frac{\Delta\varphi}{2\pi} = \frac{2f}{c}\int_0^{r_{cut}} \mu_{O,X}(r)\,dr\ , \qquad (2)$$

where $\mu_{O,X}$ – reflection indexes for O- or X-waves.

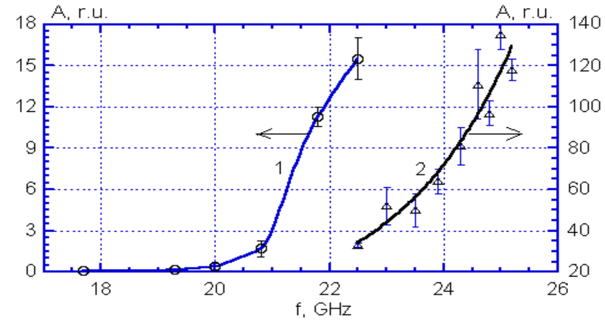

Fig.8. Frequency dependency of fluctuation amplitude: 1 – outside probing, 2 – inside probing

It was shown in this experiment that attempts to increase heating RF power by simultaneous operation of 2 RF oscillators with different frequencies are accompanied with the excitation of plasma density fluctuations in the vicinity of difference (beat) frequency of oscillators. For plasma optimization the difference frequency of 2 RF oscillators was usually in the range of 200ч300 kHz and larger then frequency band of ‘natural” density fluctuations (1ч100 kHz). The beat frequency excitation was accompanied with suppression of “natural” fluctuations (Fig.6, 9), but had no noticeable effects on plasma confinement.

Observation of “beat” frequency in the electron density fluctuation spectrum at excitation of 2 Alfven waves with different frequencies in plasma presumes an existence of density fluctuation at Alfven wave frequencies.

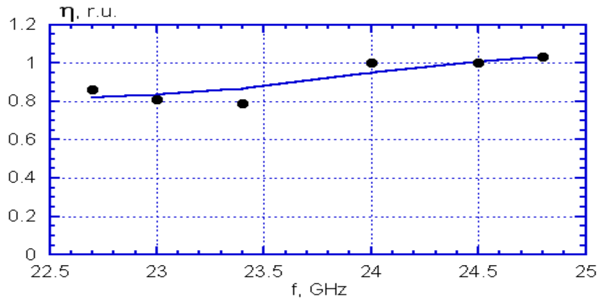

Fig.9. Dependency $\eta=P_2/P_1$ from probing frequency (P_1 is total power of fluctuation when one oscilator was switched on, P_2 is one when two oscillators where switched on)

Direct observation of high frequency (8 MHz) density fluctuations might give information on link between RF wave amplitude and RF density fluctuations and is of interest from the point of view of RF power deposition profile diagnostic.

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ОСОБЕННОСТИ ПЛАЗМЕННЫХ ФЛУКТУАЦИЙ ВО ВРЕМЯ ВЧ НАГРЕВА В ТОРСАТРОНЕ УРАГАН-3М ДВУМЯ АЛЬФВЕНОВСКИМИ ВОЛНАМИ

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Трехволновое взаимодействие наблюдалось в экспериментах на торсатроне Ураган-3М. Две ВЧ антенны с частотами Ω_1 и Ω_2 одновременно использовались для создания и нагрева плазмы, которая зондировалась микроволнами, место отражения которых перекрывало почти весь радиус. При спектральном анализе отраженных СВЧ сигналов обнаружены флуктуации плотности плазмы с частотой $\Omega_1 - \Omega_2$. При появлении колебаний на частоте $\Omega_1 - \Omega_2$ наблюдалось подавление НЧ флуктуаций. Микроволновое зондирование является полезным средством для изучения их влияния на поведение плазмы и, возможно, для воссоздания профиля поглощения ВЧ мощности.

ОСОБЛИВІСТЬ ПЛАЗМОВИХ ФЛУКТУАЦІЙ ПРОТЯГОМ ВЧ НАГРІВУ В ТОРСАТРОНІ УРАГАН-3М ДВОМА АЛЬФВЕНІВСЬКИМИ ХВИЛЯМИ

О.С. Павличенко, А.І. Скибенко, Є.Д. Волков, В.Л. Бережний, В.Л. Очеретенко, В.Г. Коновалов, А.Є. Кулага, А.П. Літвінов, І.Б. Пінос, О.В. Прокопенко, А.М. Шаповал, О.М. Швець, С.А. Цибенко

Трьоххвильова взаємодія спостерігалась в експериментах на торсатроні Ураган-3М. Дві ВЧ антени з частотами Ω_1 і Ω_2 одночасно використовувались для створення і нагріву плазми, яка зондувалась мікрохвилями, місце відбиття яких перекривало майже весь радіус. При спектральному аналізі відбитих НВЧ сигналів виявлені флуктуації густини плазми з частотою $\Omega_1 - \Omega_2$. При появі коливань з частотою $\Omega_1 - \Omega_2$ спостерігалось пригнічення НЧ флуктуацій. Мікрохвильове зондування є корисним засобом для вивчення їх впливу на поведінку плазми та, можливо, для відтворення профілю поглинання ВЧ потужності.