OSCILLATORY AND WAVE ACTIVITY IN THE RUNAWAY ELECTRONS FLOW

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The presence of the accelerated particles flow (the flow of runaway electrons) in the plasma confinement volume may case a number of different instabilities. In this work we investigate the spectrum of fluctuations in a flow of charged particles to identify the oscillatory and wave processes observed. Besides, we pay special attention to the interaction between the flow particles and plasma fluctuations. The main evidence of such interaction is the presence of modulation in the particles flow with the corresponding characteristic modulation frequency. Namely, the modulation frequency in such cases corresponds to the frequency of characteristic oscillations of the discharge plasma. Basing on this, we carried out the experimental investigations of spectrum of oscillations observed in the circuits of edge electrostatic probes during the microwave pumping pulse and also on the back edge of the magnetic field pulse.

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INTRODUCTION

In this work we study the oscillatory and wave activity of the U-3M torsatron edge plasma during a hyper thermal electrons flow formation and propagation [1, 2]. The measurements were carried out at the magnetic field pulse edges and during the RF-heating pulse which was applied at the stage of stationary magnetic field.

The flow influence on the plasma stability was widely studied on tokamaks. Thus the investigation of the edge plasma wave dynamics in presence of a hyper thermal electrons flow in stellarators represents special interest [3]. In our case the flow was generated by the magnetic field intensity variation at the edges of the magnetic field pulse (plasma confinement is performed by generation of a confining magnetic field configuration which was created by applying a current pulse to the magnetic field coils) [4, 5]. An accompanying X-ray output was also registered during the flow formation and the particles acceleration [6, 7].

Here we also continue our studies of the conditions under which a parametrical excitation of the Bernstein modes takes place. This work contains some additional information about its parameters.

EXPERIMENTAL SETUP AND DIAGNOSTIC ELEMENTS

Experiments were performed on U-3M device. U-3M is a l = 3, m = 9 torsatron with open helical divertor. The main parameters of plasma and magnetic field are R = 1 m, a = 0.13 m, B $\leq$ 1.6 T. In this experiment the magnetic field was B = 0.72 T. Plasma in U-3M is produced by absorption of a RF power (f = 8…8.6 MHz, P $\leq$ 200 kW) from 2 antennas placed inside of the helical winding near the last closed magnetic surface. Frame aerials are used to excite the RF wave in plasma.

A set of capacitive probes (3 probes) was used as the signal detectors. The probes were placed at the periphery of the confinement volume. Each probe represented a square 5×5 cm. plate of stainless steel with the thickness Δ = 0.2 cm. The plates were attached to ceramic stays and placed symmetrically on the inner surface of the magnetic field coil. The probes were placed in one cross-section of the plasma filament.

Probe 1 is situated on the inner side of the torus. Probes 2 and 3 are placed on the outer side with the 120° poloidal offset.

The signals from each of detectors were transmitted by the microwave coaxial cable to the spectrum analyzer (C4-59, C4-60). A constant bias voltage was applied on the probes through the same coaxial lines using a stabilized voltage source.

The measurements of radiation output in the sub millimeter and infrared spectral areas were carried out by the $LiNbO_3$ pyrometric detectors placed at the plasma edge.

THE MAGNETIC FIELD VARIATION CAUSES THE RUNAWAY FLOW

X-ray radiation output was observed in the absence of RF-heating at the edge of the pulse of magnetic field (Fig. 1) [8]. At the same time the particles ejection on the probes at the edge of the torus was detected. The ejection was accompanied by H_α and ECE radiation outputs. Thus, the flow of hyper thermal particles is formed at the edges of magnetic field pulse. This runaway flow is presumably created by the toroidal electric field which is induced by the variation of the intensity of magnetic field.

The flow intensity is sensitive to the working gas pressure. At the low pressures, the flow exists not only at the pulse edges but also during the phase of stationary magnetic field.

SYNCHROTRON RADIATION OUTPUT

A synchrotron radiation output was observed during the RF-power injection into the main confinement volume (Fig. 2). The amplitude level depended strongly on the radiation frequency.

The spectral measurements were carried out for the frequency range from 5 to 40 GHz (Fig. 3). It was shown that the signal level increased together with the frequency in the range from 5 to 20 GHz which included the range of the plasma waves frequency (~10…20 GHz).

The measurements of radiation output in the sub millimeter and infrared spectral areas were carried out by the $LiNbO_3$ pyrometric detectors placed at the plasma edge (Fig. 4).

The results have shown a strong noise level during the whole magnetic field pulse. On this "noisy" background a number of spikes corresponded to the RF-heating pulse and the magnetic field pulse edges were observed.

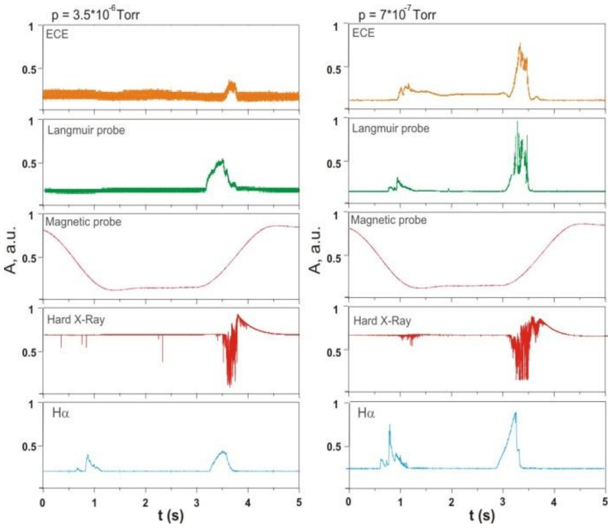

Fig. 1. The measurements carrier out without applying RF-heating at different working gas pressures

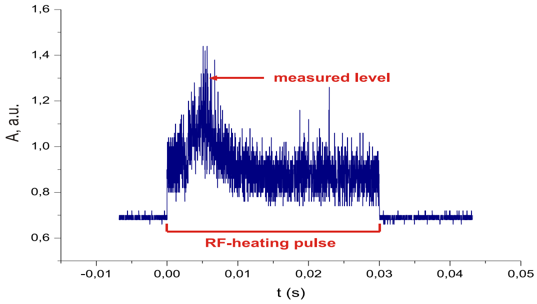

Fig. 2. The dynamics of level of synchrotron radiation observed during the RF-heating pulse

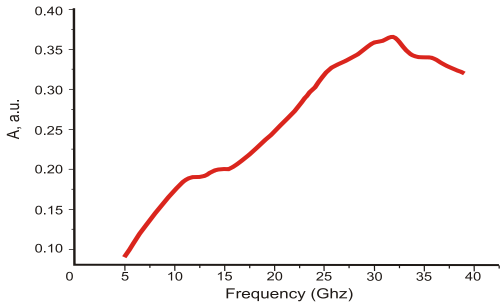

Fig. 3. The amplitude of synchrotron radiation observed during the RF-heating pulse versus the radiation frequency (f = 5…40 GHz)

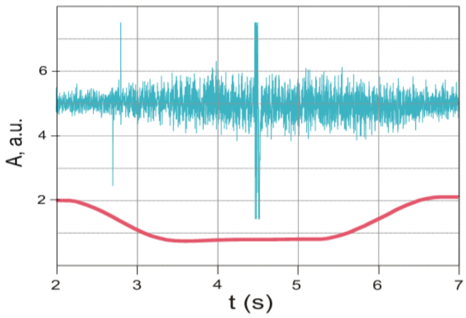

Fig. 4. Ultrahigh frequency radiation (f = 10…1000 GHz) during the whole magnetic field pulse

MICROWAVE ACTIVITY

The measurements of the diamagnetic flow dynamics and the microwave activity level (12 GHz) dynamics during the RF-heating pulse have shown a correlation in fluctuations dynamics in these two channels (Fig. 5). Such correlation may be considered as a sign of the fan instability development

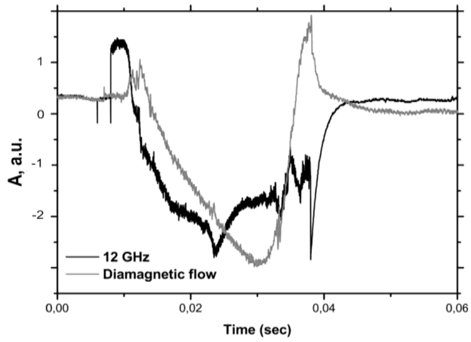

Fig. 5. Dynamics of microwave components of the current on the peripheral probe and the intensity of the diamagnetic current

It was also estimated that the microwave signal reacts noticeably on the discharge transition to the improved confinement mode just like the probe current or radiometry signal (Fig. 6) [8].

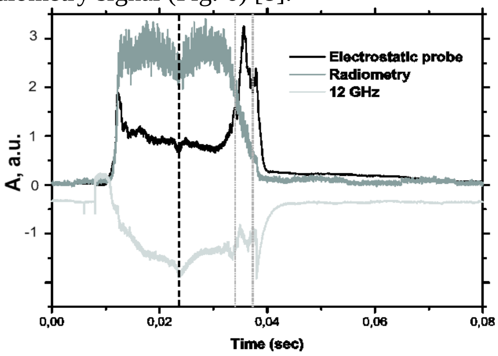

Fig. 6. Correlation of fluctuations in the signals on the peripheral current probe: its microwave components and microwave signal of reflektometer

WAVE ACTIVITY

Finally the results of experiments carried out at the vicinity of the fourth harmonic of RF-heating frequency have shown that the signal in the probe circuit passes ahead of the X-ray output. The measurements carried out for narrow frequency bands (Δf = 300 kHz) with different values of the average frequency has shown that the time shift between the X-ray output beginning and the probe current pulse reduces together with the average frequency growth (Fig. 7).

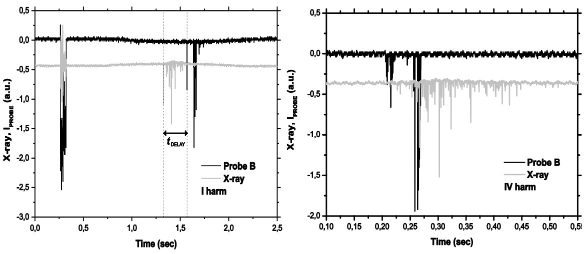

Fig. 7. Signals corresponded to different frequencies representing different harmonics of the pumping frequency appeared on the probes with different offsets according to the moment of hard X-ray output. Usually, the offsets for higher harmonics were smaller

The application of electrostatic potential of different polarities to the probes located at the system edge was also performed during the RF-heating. It caused much weaker effect but the potential polarity influence was similar to that observed in the previous case. The most pronounced influence was observed at the low-frequency area (Fig. 8).

These results give a particularly answer on the question about the way in which the fluctuations are registered by the probes. Now we can say that the information about the fluctuations is carried by an electron flow which propagates from the plasma volume to the periphery.

CONCLUSIONS

The set of oscillograms of signals from the edge electrostatic probes confirms that the runaway electrons flow interacts with the high-frequency fluctuations in plasma. As result, the particles flow experiences strong non-linear high-frequency modulation. Actually the modulation shows itself in the fact that we detect charged particles in the confinement configuration during 1.5…2 s after turning off the microwave heating. It is also remarkable that the particles which are modulated by higher harmonics of pumping frequency leave confinement volume faster than those modulated by lower harmonics.

This fact represents an evidence of wave-particle interaction because higher frequency corresponds to higher phase velocity. Consequently, particles with higher velocities leave the confinement volume faster while the confining magnetic field is decreasing (back front of the magnetic field pulse). Thus the particles modulated by higher frequencies reach edge electrostatic probes faster.

The observed behaviour could be explained as a result of generating of non-dumping modes (BGK-wave, Van-Kampen wave).

After interaction with the RF-plasma the flow becomes modulated by the particles density and velocity. Thus the spectrum of the flow current contains

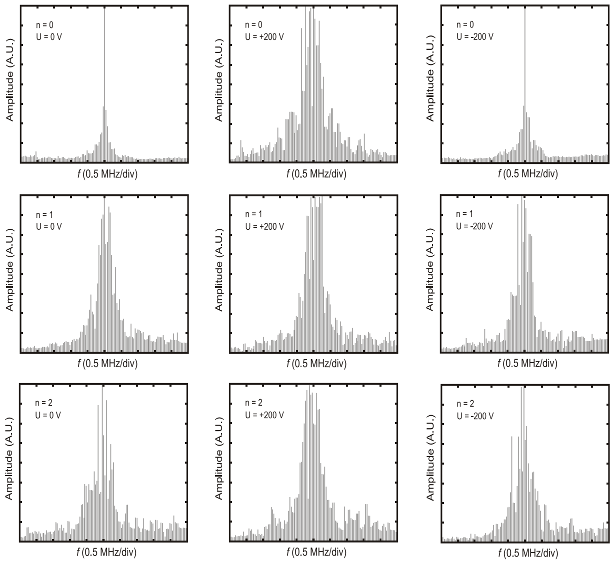

Fig. 8. The flow formation may be caused by development of plasma instabilities

the RF-heating frequency harmonics together with the parametric instability spectral components.

The presence of the fan instability is proved by increased oscillatory activity at the Langmuir frequency. These oscillations correlate with the signal from the diamagnetic loop.

The information about the oscillations observed by the edge probes during the RF-pumping pulse is carried by electron flows directed to the systems periphery. The formation of such flows is presumably the result of the plasma instability development.

In particular the synchrotron radiation (5…44 GHz) output was observed during the RF-heating pulse. At the same time an ultrahigh frequency (10…1000 GHz) radiation was registered during the whole magnetic field pulse.

Special attention was paid to hard X-ray outputs observed predominately on the edges of magnetic field pulse. The radiation energy reaches 2 MeV which proves the suggestion about formation of a high energetic particles flow of the magnetic field pulse.

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КОЛЕБАТЕЛЬНАЯ И ВОЛНОВАЯ АКТИВНОСТИ В ПОТОКЕ УБЕГАЮЩИХ ЭЛЕКТРОНОВ

И.К. Тарасов, М.И. Тарасов, Д.А. Ситников, В.В. Ольшанский, В.М. Листопад, Н.В. Лымарь, М.В. Гниденко

Присутствие в объёме удержания плазмы потока ускоренных электронов (убегающих электронов) может приводить к раскачке разного рода неустойчивостей. В данной работе речь идёт об исследовании спектра флуктуаций в потоке, а также идентификации наблюдаемых колебательных и волновых процессов. Кроме того, уделено особое внимание взаимодействию частиц потока с флуктуациями плазмы. В качестве основного признака такого взаимодействия можно рассматривать наличие в потоке убегающих электронов модуляции с частотами, соответствующими характерным частотам волновых процессов в плазме разряда. Основываясь на этих соображениях, были проведены исследования спектра колебаний тока в цепи периферийных электростатических зондов как во время импульса ВЧ-накачки, так и на заднем фронте импульса магнитного поля.

КОЛИВАЛЬНА І ХВИЛЬОВА АКТИВНОСТИ В ПОТОЦІ ВТІКАЮЧИХ ЕЛЕКТРОНІВ

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Присутність в обсязі утримання плазми потоку прискорених електронів (втікаючих електронів) може призводити до розгойдування різного роду нестійкостей. У даній роботі мова йде про дослідження спектра флуктуацій в потоці, а також ідентифікації спостережуваних коливальних і хвильових процесів. Крім того, приділено особливу увагу взаємодії часток потоку з флуктуаціями плазми. В якості основної ознаки такої взаємодії можна розглядати наявність в потоці втікаючих електронів модуляції з частотами, відповідними характерним частотам хвильових процесів у плазмі розряду. Грунтуючись на цих міркуваннях, були проведені дослідження спектра коливань струму в ланцюзі периферійних електростатичних зондів як під час імпульсу ВЧ-накачки, так і на задньому фронті імпульсу магнітного поля.