THE DYNAMICS OF 3D DIOCOTRON WAVE DURING THE “HOT“ ELECTRON FLOW PROPAGATION IN THE DRIFT SPACE

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The longitudinal dynamic effect on the diocotron wave evolution was clarified. The main features of the plasma particles trapping and confining during the ‘hot’ electron beam propagation through the space of drift were studied.

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INTRODUCTION

A huge amount of publications were dedicated to charged particles confinement in a cylindrical Penning trap. Such systems allowed to observe and to study a number of interesting effects in the plasma column dynamics. Unfortunately Penning traps weren’t so useful in studying the effects developed during the charged particles flow propagation along the magnetic field axis. For these investigations we have used a cylindrical setup without the axial confining field. In our case the width of the flow particles distribution by longitudinal velocities is close by its magnitude to the average longitudinal velocity. The experimental results have shown the diocotron instability development [1]. The diocotron waves had pronounced azimuthal and longitudinal components. It was also detected that the instability development is localized in the potential dip which is created by the flow particles spatial charge.

1. EXPERIMENTAL SETUP

The electron flow passed through the cylindrical drift tube in longitudinal magnetic field (H = 890…2100 Oe) from the indirectly heated injector cathode to the particles collector (Fig. 1). The injection was carried out by applying a negative potential pulse (injection pulse) to the cathode.

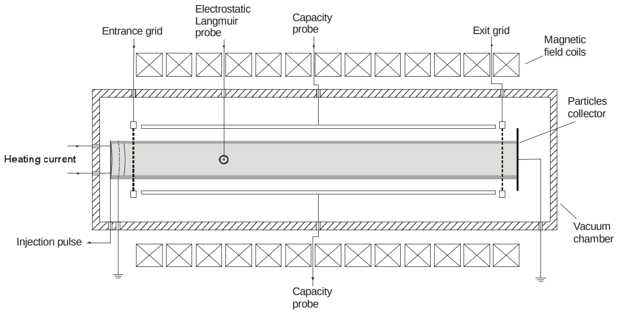

Fig. 1. The schematic of experimental setup

The flow current is measured by metal grid installed at the drift tube entrance and particles collector placed at the system end. The diocotron oscillations are studied by a couple of capacitive probes and mobile Langmuir probe. The entrance diafragm was present only during the experiments with the hollow cylyndrical electron flow.

2. EXPERIMENTAL RESULTS

In both types of the flow radial profile (cylindrical and tubular) the generation of low-frequency diocotron oscillations was observed.

The width of the electron distribution by longitudinal motion energies was equal by the order of magnitude to the average kinetic energy of the flow longitudinal motion. The distribution had two maxima corresponded to electron energy $E_e \approx 15$ eV and $E_e \approx 30$ eV.

The spatial distribution of electrostatic potential also exhibited two maxima under condition of high enough injection current. In the case of tubular profile the potential measurements were averaged by duration of the injection pulse. The electron flow was shaped as a hollow tube. The measurements of the flow current distribution have shown formation of so called ‘reverse flow’ at both external and internal edges of the electron tube (Fig.2).

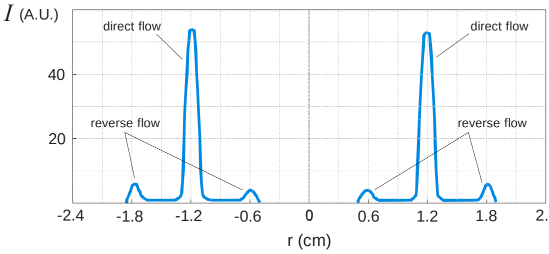

Fig. 2. The flow intensity radial

Thus one could conclude that the particles at the flow edges have the lowest energies of the longitudinal motion. So the potential barrier formed at the electron tube edges. Such a barrier creates a reflecting electrostatic potential which decelerates the flow particles and finally forms the reflected ‘reverse flow’.

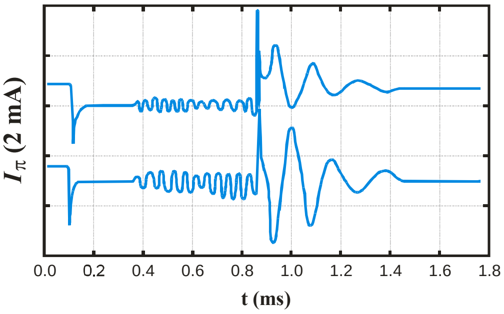

Fig. 3. The dynamics of diocotron oscillations observed by the capacity probes

The potential barrier obviously formed as the result of influence of the electron tube spatial charge electric field on the slowest part of the flow particles.

So called diocotron oscillations represent an azimuthal motion of non-symmetric bunch (or bunches) of the flow electrons shifted from the system axis (Fig. 3). The generation of diocotron waves was observed during the pulse of the flow injection. The waves frequency was in the range $f = 10\ldots50$ kHz.

After the flow injection breakdown some sort of damping diocotron wave was observed. Such waves were named ‘residual’. Their frequency was relatively low ($f = 1\ldots10$ kHz). It is also useful to note that the injection breakdown is followed by a jump-like change of the wave amplitude.

The experiments with the cylindrical electron flow were carried out on the same experimental setup that was used earlier to study the dynamics of tubular flow. The only difference between these two experiments was absence of the entrance diaphragm which cut off the central part of the flow.

growth of the magnetic field intensity here leads to decrease of the damping rate of residual waves.

In our earlier papers we presented the results of experiments carried out with additional beam injection after the main injection pulse breakdown [2,3]. It was shown that such injection may turn back the damping process and provide the wave “pumping” or echo-like effect.

Another interesting effect is jumpwise changing of the residual wave amplitude observed after a ‘short’ additional beam injection during the residual wave damping (Fig. 5).

The effect of additional injection in this case depends on the polarity of the oscillations half-period in which it was carried out. Assuming that the geometry of both main and additional injected flows (beams) is similar we conclude that this effect is caused by the longitudinal dynamics of the diocotron waves.

To explore the main features of axial dynamics of the diocotron waves the probe measurements in the different points of the drift tube were carried out.

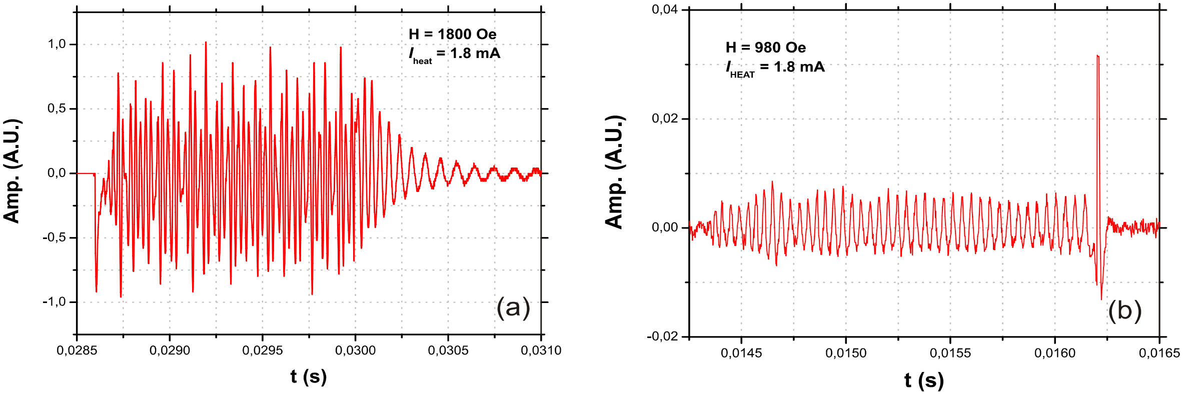

Fig. 4. The dinamics of diocotron oscillations during the cylindrical beam propagation through the drift chamber for high (a) and low (b) magnetic field intensitie

The main purpose of this experiment was to observe a more pronounced non-linear dynamics of the diocotron waves.

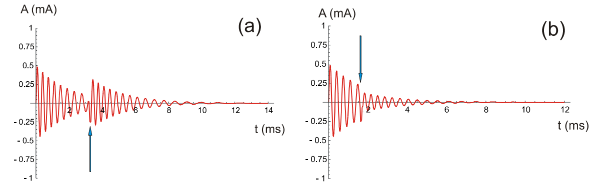

Fig. 5. The effect of short additional beam injection

The development of such non-linear effects was stimulated by the presence of additional space charge in the central part of the flow. Also one of the key issues was to find out the connection between the longitudinal dynamics of the flow and diocotron waves behaviour. The experiments with cylindrical (non-tubular) flow exhibited strong nonlinear effects. In particular a pronounced amplitude modulation of the diocotron oscillations was observed during the flow injection (Fig. 4). The modulation depth and frequency increased together with the magnetic field intensity. For H = 980 Oe, for example, $f_{MOD} \approx 2\ldots3$ kHz. The residual diocotron waves were also observed in this regime. The

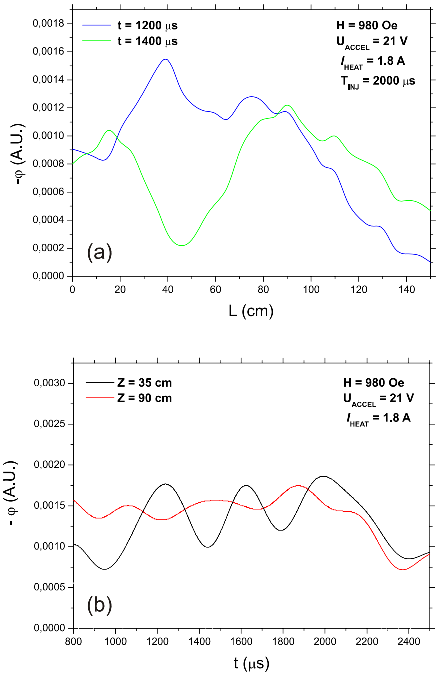

Fig. 6. Longitudinal distribution of electroctatic potential in the drift tube (a) and the self-consistent trap oscillstions (b)

The probes were separated in the axial direction. Both the averaged longitudinal potential distribution and the potential fluctuations in different points of the drift chamber were studied. It was shown that the potential distribution form depends strongly on the injection parameters and time (Fig. 6.).

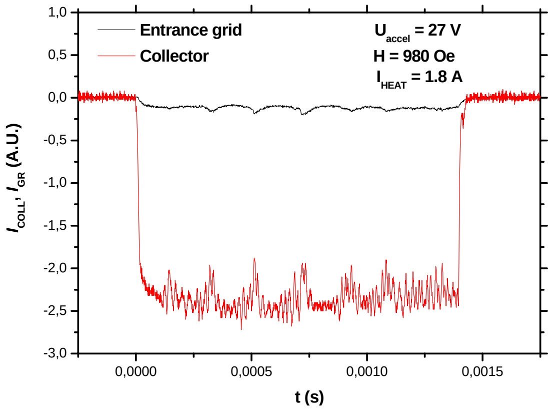

Fig. 7. The flow current on the collector and entrance grid electrodes

In particular, the configuration with two space charge potential barriers is not stable. Actially the longitudinal distribution of the electrostatic potential “oscillates” with some small enough frequency ($f \approx 3$ kHz). It is also remarkable that the potential oscillations in the points corresponding to the mentioned above potential barriers are counter-phased. Such dynamics may cause the separation of the electrons trapped between the potential barriers by their longitudinal velocities. The oscillations of the potential dip walls cause the fast particles ejection along the magnetic field axis. Thus the most high-energetic particles leave the self-consistent confining configuration formed by the flow particles space charge. This suggestion is supported by the results of electron current measurements on the system collector and entrance grid. The current curves exhibit a number of spike-like oscillations which frequency corresponds to the frequency of the potential barrier oscillations and the amplitude modulation frequency of the diocotron oscillations (Fig.7).

CONCLUSIONS

A number of conclusions were made from the given experimental results.

In the case of homogeneous electron flow profile the diocotron oscillations pattern has a pronounced stochastic nature.

The diocotron wave has a pronounced three dimentional dynamics (proved by the experiments with an additional beam injection).

In both cylindrical and tubular flows the excitation of diocotron wave was followed by development of modulation instability.

The diocotron instability is localized in the spatial area in which the self-consistent electron trap is formed

The self-consistent electron trap is formed by a pair of potential barriers which oscillate in opposite phases

The frequency of barrier oscillations is close to modulation frequency of the diocotron oscillations and to the frequency of the flow particles ejection from the self-consistent trap

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ТРЕХМЕРНАЯ ДИНАМИКА ДИОКОТРОННОЙ ВОЛНЫ В ПРОЦЕССЕ ПРОХОЖДЕНИЯ «ГОРЯЧЕГО» ПОТОКА ЭЛЕКТРОНОВ В ПРОСТРАНСТВЕ ДРЕЙФА

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Определена роль продольной динамики в эволюции диокотронной волны. Также были изучены основные особенности захвата и удержания частиц при прохождении «горячего» электронного потока в пространстве дрейфа.

ТРИВИМІРНА ДИНАМІКА ДІОКОТРОННОЇ ХВИЛІ В ПРОЦЕСІ ПРОХОДЖЕННЯ «ГАРЯЧОГО» ПОТОКУ ЕЛЕКТРОНІВ У ПРОСТОРІ ДРЕЙФУ

М.І. Тарасов, І.К. Тарасов, Д.А. Сітніков

Вивчено роль поздовжньої динаміки в еволюції діокотронної хвилі. Досліджено ключові особливості захоплення та утримання частинок при проходженні «гарячого» електронного потоку в просторі дрейфу.