THE OBSERVATION OF LANDAU-LIKE DAMPING AND DIOCOTRON ECHOES IN A PURE ELECTRON PLASMA

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This paper is dedicated to the additional experimental study of the diocotron wave Landau damping, during and after the main electron beam injection pulse. Also, it contains some data on injection of additional electron beam.

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INTRODUCTION

The phenomena of diocotron wave collisionless damping and diocotron echo were studied intensively during the second half of twentieth century. One of the most interesting works containing theoretical analysis of collisionless (Landau-like) diocotron wave damping in terms of fluid dynamics was made by Levi. [1]. Numerical analysis of the corresponding 2-D linearized incompressible fluid equations was given in [2]. These equations were composed and solved for cylindrical pure electron plasma and the results of such solution were also expressed in density profiles. Recently, a couple of theoretical works were published dedicated to 2D vortex collisionless damping [3,4].

This paper presents the results of experimental study of diocotron wave collisionless damping in a pure electron plasma. The damping was observed during the longitudinal transportation of hollow cylindrical electron beam trough the cylindrical drift chamber. We also injected an additional electron beam. Both beams were strongly dim in velocities.

The results of preliminary experimental study have shown several beam transport features of such configuration. The configuration provides beam transportation through areas of uniform and non-uniform longitudinal magnetic field. The motion of beam particles reorganizes during the injection into the area of non-uniform magnetic field. Considerable part of the beam electrons participates in azimuthal motion and therefore the group of particles with smaller axial and higher azimuthal velocity is formed. Thus we can distinguish two groups of injected particles: the passing particles group (i) and the confined group (ii). The passing particles have higher axial velocity and this group contains approximately 90% of all injected particles. During the passage these electrons are forming double-dips longitudinal profile of potential [5]. Such profile represents a configuration of electron trap. The particles of the second group (10% of all injected particles) are confined in this trap for rather long time (injection pulse duration plus diocotron wave damping time).

EXPERIMENTAL DESIGN AND SETUP

The scheme of experimental setup is shown on Fig. 1. The main beam was generated by the electron gun. The gun consists of cathode heated indirectly and anode metal grid. The injection of electron beam was achieved by applying a positive voltage pulse (injection pulse) to the anode grid. The shape of anode grid was chosen specially for obtaining the required shape of the electron beam (hollow cylinder). The main beam was injected into the drift space (a brass tube of length L = 150 cm. and diameter D = 4 cm), with flat grids at the entrance and the exit. The tube was cut parallel to the generatrix into two equal halves and was made up of two sectors of angular extent 180° (π - electrodes). Both sectors were attached to the leads and used for diagnostic purposes. The thickness of injected beam was Δ = 1-2 mm and its diameter was d = 2 cm. The beam energy was 20-80 eV. The constant longitudinal magnetic field had a strength of H = 100-2000 Oe. The magnetic field varied over the length of the drift tube by less than 5% so we assumed it to be uniform inside the drift tube. It is also necessary to note that injector was located near the entrance to the drift tube at the area of non-uniform magnetic field. The range of working pressures was 10^{-4}-10^{-7} Torr.

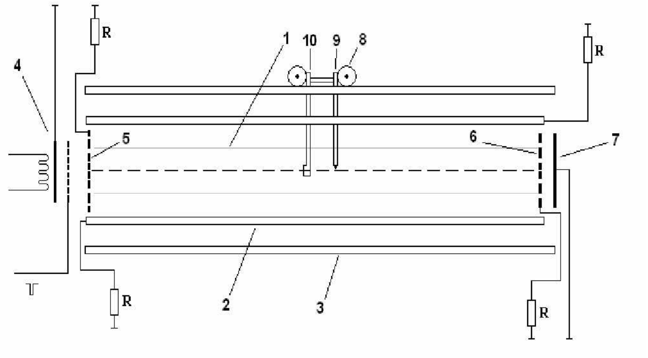

Fig.1. Schematic of the experimental setup: 1) electron beam; 2) drift tube; 3) vacuum chamber; 4) electron gun; 5) entrance grid; 6) exit grid; 7) collector; 8) carriage; 9) high-frequency Langmuir probe; 10) electrostatic analyzer

Diagnostic measurements of axial distribution of electrostatic potential were made by high-frequency Langmuir probe. The probe was placed on the mobile carriage together with a multigrid electrostatic analyzer. The occurrence and evolution of diocotron oscillations was detected by π – electrodes. In this experiments we generated diocotron modes with the azimuthal wave number l = 1. In this case the oscillations of current induced on each of the π – electrodes are in opposite phases. The flat grids at the entrance and exit of the drift tube were used for measuring of current input and output.

Preliminary experiments have shown the existence of diocotron oscillations during the pulse of injection. As it was predicted, we have detected the wave with $l = 1$. By measuring the frequency of diocotron oscillations we have made some calculations of electron density.

The injection of additional beam was made by the same electron gun. This beam had the same geometrical characteristics with the main beam. The duration of the additional beam was small enough to carry out a transient interaction between beam particles and existing diocotron waves. This beam had the similar distribution of particles by velocities with the main beam.

EXPERIMENTAL RESULTS

We monitored the behavior of the system while varying the values of magnetic field intensity (H) and injection current (I). As a result, after the pulse of injection, we observed the damping of diocotron wave with different increments. Depending on the varied parameters the damping length was varying from 0.1 ms. to 30 ms. The value of minimal injection pulse duration required for observing such damping was 500 μs. In most cases the oscillations were coherent from one pulse to another.

Remarkably, the most of oscillation damping processes were followed by a small voltage pulse on the π-electrode produced by the particles ejection the drift tube wall. Sometimes such pulse was observed at once after the oscillation damping process but in most cases it follows with certain delay.

Fig.2. represents the oscillograms of the damped diocotron oscillations with the different shape of envelope. In the first case (Fig. 2,a) the amplitude decreases exponentially. Second case (Fig. 2,b) represents the damping process in which amplitude oscillates before the diocotron oscillations are finally damped. Particles density was decreasing linearly during the whole damping process. The range of half-damping time variation for different parameters of magnetic field and injection current was 0.1 – 15 ms.

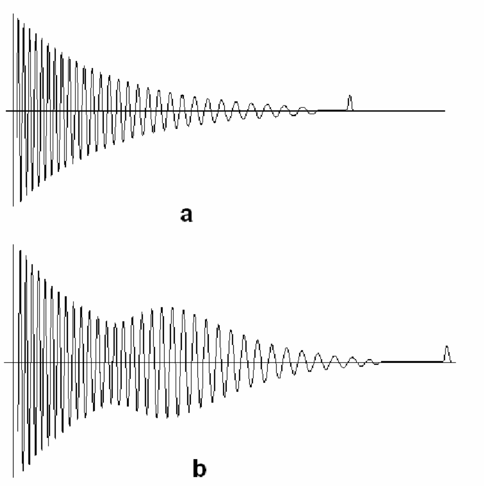

Fig.2. Diocotron wave collisionless damping pattern:
a – exponential damping; b – collisionless damping with amplitude oscillations

The case presented on Fig. 3 differs from considered above only by the presence of additional beam. The duration of this beam was $\tau_B \sim T_o$, where T_o is the period of damped diocotron oscillations in the collapsing electron plasma. The beam was injected with a small delay after the beginning of damping process when the wave amplitude was still high.

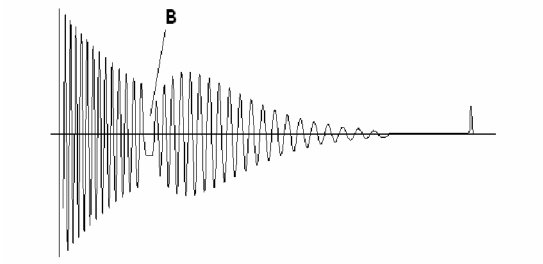

Fig.3. The damped diocotron wave amplified by the injection of additional beam (B)

This oscillogram shows that injection of additional beam switches the interaction between damped waves and particles into a wave amplification stage. Such result may be interpreted as the effect of electric charge of the additional beam. The density of charged particles increases due to injection of additional beam and therefore the velocity of particle rotation increases too. This results in amplitude growth stage with further absolute damping.

Fig. 4 displays oscillograms corresponding to injection of additional beam with duration $\tau_B \leq T_o/2$.

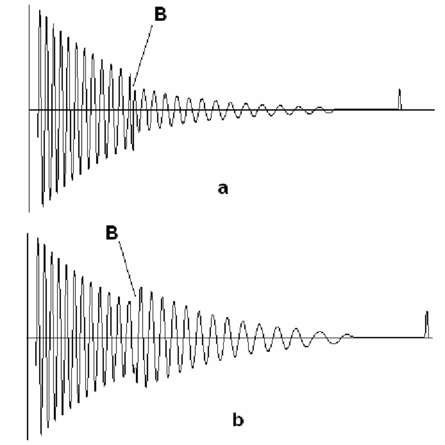

Fig. 4. Wave-beam interactions during the injection of low-duration additional beam (B) in different phases

In this case the injection was following the outset of damping process with a longer delay. From given oscillograms one can conclude that the resulting effect of interaction between the wave and the beam depends on polarity of the diocotron wave half-period that corresponds to the injection time. If additional beam was injected during the positive half-period the stage of growth observed. In opposite case one would observe increased damping.

The explanation of such effect may be given by consideration of beam particles modulation by the diocotron wave and generation of Van-Kampen wave. Actually the injection of additional beam in a half-period with increased particles density provides the amplitude growth. The similar injection in a low density half-period produces additional damping.

The next oscillogram (Fig. 5) was obtained almost under the same conditions with previous. The main difference lays in a bigger delay before the additional beam injection.

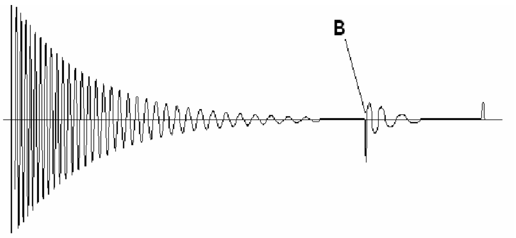

Fig.5. The repeated excitation of diocotron wave due to the injection of the additional beam (B)

The injection of additional beam was provided after the absolute damping of diocotron wave. In this case the repeated excitation of diocotron wave was observed after the additional beam injection. This effect occurs if the injection delay is longer than the damping time and smaller than the time of electron ejection pulse occurrence. It is also necessary to note that such phenomenon was not observed if the main beam was not injected. This effect has the same nature with diocotron echo despite of the fact that it is the result of the additional beam injection.

CONCLUSIONS

From the given experimental results we conclude that considered configuration becomes a scope for a number of different linear and non-linear effects, such as:

- linear and non-linear collisionless damping of the diocotron wave.
- Van-Kampen wave generation and the phenomenon of diocotron echo.
- Different cases of interaction between wave and beam.

However, the presence of these effects in case of dicotron wave generation with l = 1 contradicts with regulations introduced in [1] and requires further theoretical study.

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НАБЛЮДЕНИЕ ЗАТУХАНИЯ ЛАНДАУ И ДИОКОТРОННОГО ЭХА В ЧИСТО ЭЛЕКТРОННОЙ ПЛАЗМЕ

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Уделено внимание дополнительному экспериментальному изучению явления затухания Ландау диокотронной волны. Исследовались диокотронные колебания во время и после окончания импульса инжекции. Также представлены некоторые данные, полученные при проведении экспериментов с инжекцией дополнительного пучка электронов.

СПОСТЕРЕЖЕННЯ ЗАГАСАННЯ ЛАНДАУ ТА ДИОКОТРОННОЇ ЛУНИ У СУТО ЕЛЕКТРОННІЙ ПЛАЗМІ

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Увага зосереджена на додатковому експериментальному вивченню явища загасання Ландау диокотронної хвилі. Вивчалися диокотронні коливання як підчас, так і після імпульсу інжекції. Також представлено деякі дані, отримані при проведенні експериментів з інжекції додаткового пучка електронів.