STUDY OF COLLISIONLESS DAMPING OF DIOCOTRON OSCILLATIONS IN ELECTRON PLASMA

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Damping of diocotron waves in plasma has been studied. The waves are assumed to be excited in the course of the passage of a cylindrical beam of electrons, which are characterized by a certain dispersion of their velocities, through a drift chamber. The damping concerned is observed in the decaying electron plasma after the injection has been terminated. The results of experiments, which evidence the collisionless and reversible nature of this damping, have been reported. The damping process has also been demonstrated to run in either a linear or a nonlinear mode, depending on the initial amplitude of diocotron oscillations. In addition, a few graphic dependences for several damping parameters have been presented.

1. Introduction

The study of the collisionless damping of diocotron waves is a fundamental problem of modern plasma physics. The versatile researches of this phenomenon have been in progress for more than thirty years. The corresponding theoretical basis was set in work [1], where the results of theoretical researches concerning the conditions necessary for the emergence of the above-mentioned damping and the analysis of its characteristics were presented. Later on, a number of experimental researches dealing with the collisionless damping of diocotron waves in an electron plasma with cylindrical geometry were fulfilled, and a partial coincidence with the results of relevant theoretical studies was pointed out [2–4].

A series of experiments concerning the controlled excitation and the free damping of diocotron waves gave rise to a construction of a number of charged-particle density profiles [5] which immediately characterized the damping process and the phenomenon of diocotron echo in the electron plasma with cylindrical geometry.

This work deals with studying the processes of damping of diocotron oscillations which arise when a beam of electrons with a strong velocity dispersion passes through a drift chamber. It should be emphasized that, in our case, the beams had cylindrical shape and were injected into the drift chamber in the direction along the magnetic field. The main purpose of the work consisted in elucidating the nature of the damping observed and obtaining the relations for its characteristic parameters.

2. Experimental Researches

Experimental studies were fulfilled making use of an installation, the scheme of which is depicted in Fig. 1. The pressure in the chamber was maintained at a level of 10^{-6}–10^{-7} Torr. The electron beam was accelerated by the potential $U_{\rm ACCEL} = 20 \div 30$ V. The strength of the longitudinal magnetic field reached 10^3 Oe. Charged particles in the beam were characterized by a broad dispersion of their velocities.

A number of characteristic features distinguishes our experiment from those made earlier in other researches. Among them, the following factors are to be especially emphasized: free oscillations were excited, when a cylindrical beam of electrons with a dispersed velocity distribution propagated in the drift space; diocotron wave damping was studied at the decay of the electron plasma (when the injection of the electron beam had been terminated); modifications to the damping process were carried out by methods different from those applied earlier in the works on this topic [3–5].

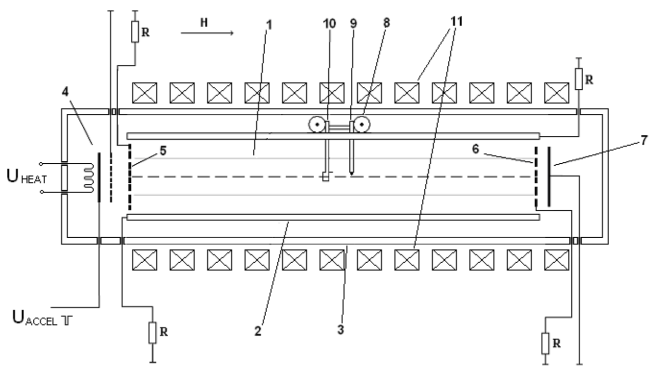


Fig. 1. Experimental installation: *1* – electron beam, *2* – drift chamber, *3* – vacuum chamber, *4* – injector, *5* – input grid, *6* – output grid, *7* – collector, *8* – mobile platform, *9* – Langmuir probe, *10* – electrostatic analyzer

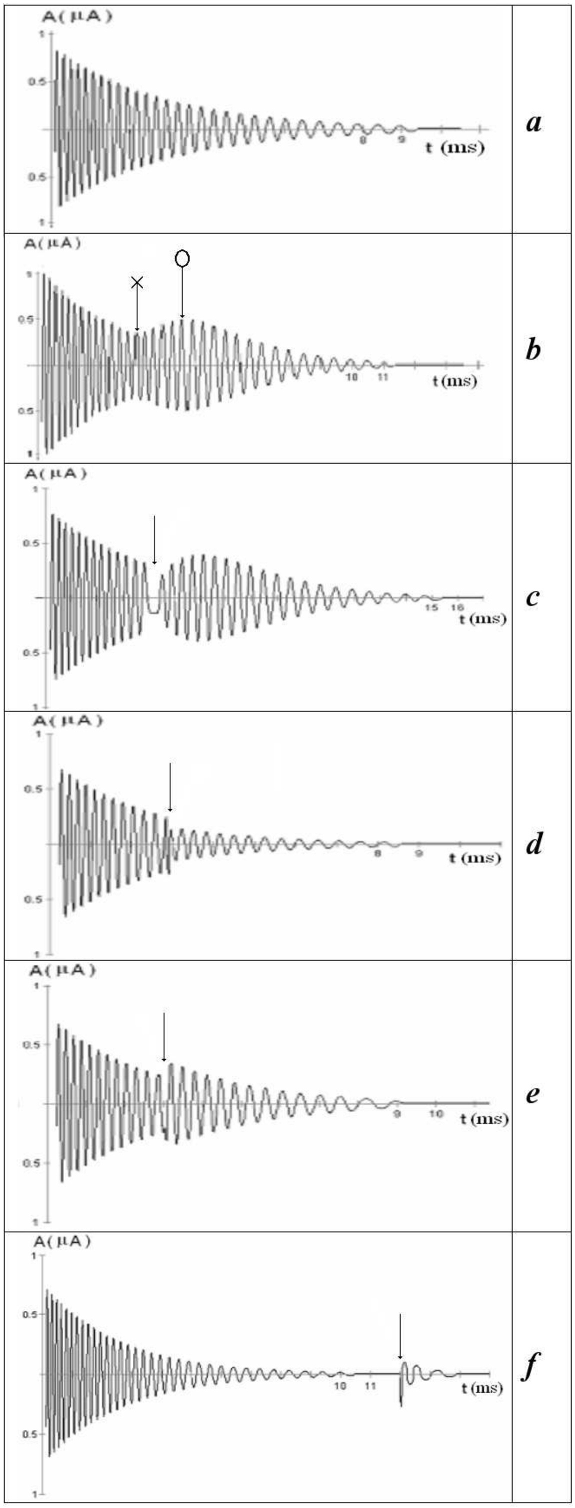


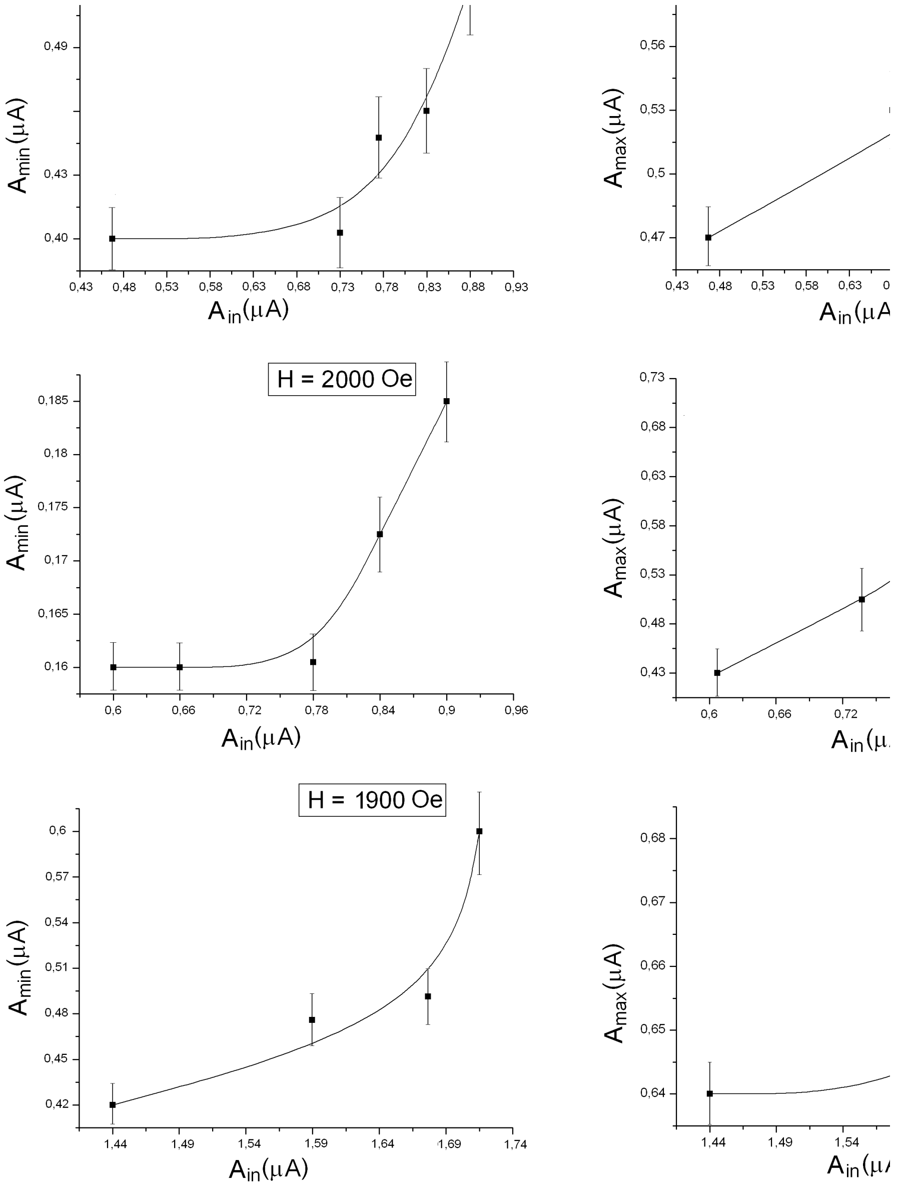
Fig. 2. Diocotron wave damping in the longitudinal magnetic field $H = 1$ Oe. Arrow × in panel b marks the point ($t_{\min}$, $A_{\min}$), arrow O in the same panal – the point ($t_{\max}$, $A_{\max}$), and arrows in panels c to f mark the moment of additional beam injection

Injection of the electron beam with a dispersed velocity distribution into the drift chamber excited diocotron oscillations inside. After the injection having been terminated, the oscillations faded (Fig. 2,a). Such damping could have been a result of a reduction of the number of charged particles in the chamber. However, numerous experimental runs with varied parameters revealed a mode (Fig. 2,b), when oscillations faded down to a certain amplitude and then, suddenly, started swinging. Owing to this reexcitation, the amplitude of oscillations increased and, having reached a local maximal value, started to decrease back, and oscillations ultimately faded. The very fact of the existence of such a damping mode allowed an assumption about the collisionless character of the observed damping to be made. In order to check this assumption, a series of experiments with the injection of an additional beam were fulfilled. The additional beam injection was executed making use of the same injector that was applied before to generate the main beam. Almost all corresponding characteristic parameters of the additional and main beams coincided with one another, except for the duration of the injection pulse, which was much narrower in the additional-beam case.

Let us start our consideration from experiments, where the duration of an injection pulse in the additional beam was rather long (longer than the period of diocotron oscillations). In this case, right after the additional beam had been injected, a transition from the stage of diocotron oscillations damping to the stage of their swinging was observed (Fig. 2,c). Having reached a certain level of amplitude, the oscillations came back again to damping.

Such a behavior of the system can be explained by the fact that damped oscillations, which were observed after the termination of the main injection pulse, had the azimuthal wave number $l = 1$ (the first mode). The additional injection with the indicated parameters would bring about the restoration of a continuous radial profile in the cylindrical beam, in which, according to the results of works [1,2], the oscillations belonging to the indicated mode did not fade out but, on the contrary, became swung.

In the following experiments, the duration of the additional injection pulse was shorter (shorter than the half-period of diocotron oscillations). Due to such an injection, the amplitude of oscillations drastically changed (Figs. 2,d and e). It either sharply increased or decreased, depending on the polarity of the oscillation half-period, which the injection event fell within. This effect testifies, first of all, to a strong modulation of



a *b*

Fig. 3. Dependences of the minimal and maximal amplitudes on the initial one at the nonlinear damping of diocotron waves for various values of the longitudinal magnetic field strength

particle concentration in the drift space, which is also a typical attribute of collisionless damping.

Another characteristic phenomenon was observed, when the time delay of an additional injection pulse relative to the main one was increased. The delay interval was so established that the additional injection was made at a moment when diocotron oscillations had ultimately died away. As a result, provided that the choice of experimental parameters was made properly, the phenomenon of diocotron wave regeneration was

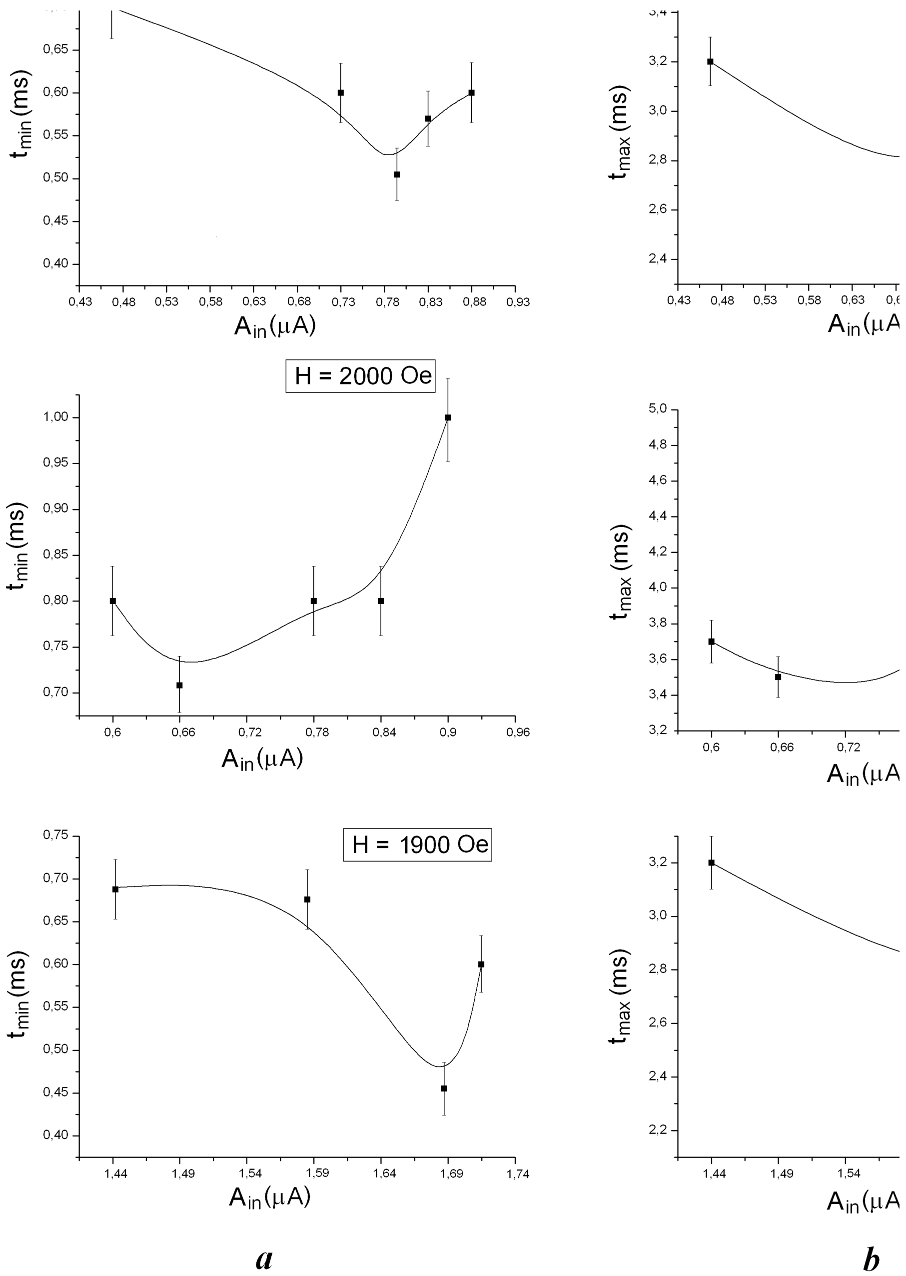


Fig. 4. The same as in Fig. 3, but for characteristic temporal parameters describing the nonlinear damping of diocotron waves

observed (Fig. 2,*f*). It should be especially emphasized that the effect was observed only if both the main and additional beams were present. A similar phenomenon cannot be observed in the case of completely dissipative damping, which, in turn, is an important argument in favor of its partial collisonlessness.

The results obtained allow us to confirm that the damping of diocotron oscillations observed after the termination of the main beam injection has a partially collisionless character. Namely, along with the damping that occurs owing to a reduction of the number of particles in the drift chamber, the collisionless damping of waves also takes place due to their interaction with the rest of particles from the decaying electron beam.

It is worth noting separately that the classical scenario for the nonlinear collisionless damping predicts several periods of amplitude modulation, whereas only one period was revealed in this work. The reason for such a discrepancy is the fact that the object of our researches was a decaying plasma. Therefore, in what follows, we consider the results of experimental researches dealing with the diocotron wave damping characterized by a single period of amplitude modulation. As characteristic parameters, we chose the following ones: the minimal amplitude, which the wave became first damped to, and, while attaining it, a transition to the excitation stage started; the maximal amplitude, which was achieved at the excitation stage; and the initial amplitude of diocotron oscillations (the amplitude of oscillations at the moment of the main injection termination).

The dependences of the minimal and maximal amplitudes of damped diocotron oscillations on the initial one for various values of the longitudinal magnetic field strength are depicted in Figs. 3,*a* and *b*, respectively. Analogous dependences for the time intervals needed for the minimal and maximal amplitudes to be reached are presented in Fig. 4.

Figures 3 and 4 demonstrate that, in the case of nonlinear collisionless damping, a definite value of the longitudinal magnetic field strength corresponds to the maximal degree of amplitude modulation, irrespective of the initial amplitude value. At the same time, the dependences for time intervals testify that their maximal values correspond to the maximal degree of modulation.

A comparison of experimental data with the results of computer simulation concerning the nonlinear Landau damping in a plasma wave [6] evidences similar behaviors of the amplitude parameters describing the nonlinear damping. What is at issue is, first of all, a similarity between the character of the dependences displayed in Fig. 3 with the corresponding curves exhibited in the work mentioned above.

As a key parameter which characterizes the linear damping (the damping without amplitude modulation), the time interval, within which the damping occurs, was selected. The data obtained allowed us to plot the dependences of this time interval value on the magnitude of acceleration potential in the injector for various values of the magnetic field strength (Fig. 5). From the plotted curves, one can see that an increase of the longitudinal magnetic field strength results in the growth of the damping time interval at every value of the accelerating potential. The reason for this phenomenon lies in the influence of the magnetic field strength variation on the beam geometry and, as a consequence, on the number of particles located at the resonance radius.

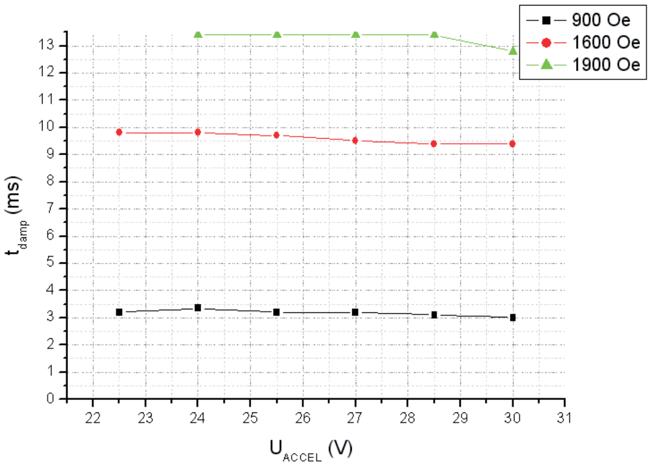


Fig. 5. Dependences of the time interval of the diocotron oscillation damping in the linear mode on the acceleration potential of the injector

3. Conclusions

A series of experiments aiming at elucidating the character of the diocotron wave damping, which is observed in the drift chamber after the electron beam injection has been terminated, has been carried out. As the main method to affect the behavior of residual electrons, the injection of an additional electron beam was selected. The characteristic damping parameters have also been measured under various injection conditions. Experiments with additional electron injection testified that the damping observed has a partially collisionless character. The dependences obtained for the characteristic amplitude and temporal parameters of the nonlinear damping evidence their strongly pronounced dependence on the longitudinal magnetic field strength in the drift chamber. In the case of the nonlinear damping (the damping with amplitude modulation), the characteristic damping parameters depend non-monotonously on the strength of the longitudinal magnetic field. At the same time, these dependences decrease monotonously in the linear damping mode. In addition, a similarity between the results obtained by us for the behavior of the amplitude parameters describing the nonlinear damping and the data obtained in work [6] was pointed out.

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ДОСЛІДЖЕННЯ БЕЗЗІТКНЮВАЛЬНОГО ЗАГАСАННЯ ДІОКОТРОННИХ КОЛИВАНЬ У ЕЛЕКТРОННІЙ ПЛАЗМІ

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Р е з ю м е

Досліджено загасання діокотронних хвиль, збуджених у процесі проходження циліндричного розмитого за швидкостями пучка електронів у камері дрейфу. Досліджуване загасання спостерігається після закінчення інжекції у електронній плазмі, що розпадається. Наведено результати експериментів, що вказують на беззіткнювальну природу загасання та оборотність цього процесу. Показано також, що в залежності від початкової амплітуди діокотронних коливань, загасання відбувається як у лінійному, так і в нелінійному режимах. Крім того, наведено декілька графічних залежностей для низки параметрів загасання.