ACCUMULATION AND CONFINEMENT OF ELECTRONS IN A PENNING TRAP WITH A CENTRAL ELECTRODE

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In this work results of experimental and theoretical research of electron accumulation at the injection of a tubular electron beam with strong spread over velocities in a Penning trap with a central electrode are presented.

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1. INTRODUCTION

Non-neutral plasma consisting of one-grade particles has still represents scientific interest. It is caused by relative simplicity of its confinement in external electromagnetic fields. For such confinement a number of devices is used, one of which is Penning-Malmberg trap. The description of this trap may be found in [1, 2, 3]. The improvement of particles confinement in this type of trap was made due to artificial particle capture in a rotating electric field [4, 5, 6]. It was shown, that such method allows operating the trapped plasma and considerably increases its confinement time. The forces which are limiting particles motion along the external magnetic field not necessarily to be external. Such forces may have a self-consistent character and occur as result of a various dynamical processes. For example, such processes accompany the hot electron beam transport with the presence of magnetic field [7,8]. Self-consistent systems of charged particles accumulation and confinement may become an alternative to traditional systems and also gives some information about a number of natural phenomena.

In this work the possibility of self-consistent and classical confining systems combination is studied.

2. EXPERIMENTAL 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 6 heated indirectly and anode 7 metal grid. The injection of electron beam 1 was achieved by applying a negative voltage pulse (injection pulse) to the cathode. The shape of anode grid was chosen specially for obtaining the required shape of the electron beam (hollow cylinder). The beam was injected into the drift space 2 (a brass tube of length L = 150 cm. and diameter D = 4 cm), with flat grids at the entrance and the exit (8,9). The tube 2 was cut parallel to the generatrix into two equal halves and was made up of two sectors of angular extent 180º (π - electrodes). Both sectors were attached to the leads and used for diagnostic purposes. Filamentary metallic electrode 10a was placed on the axis of drift tube. This electrode10 was substituted later by five metallic tubes (D = 0.6 cm, L = 30 cm). The thickness of injected beam was Δ = 1…2 mm and its diameter was d = 2 cm. The beam energy was 20…50 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 working pressures were $10^{-4}…10^{-7}$ Torr.

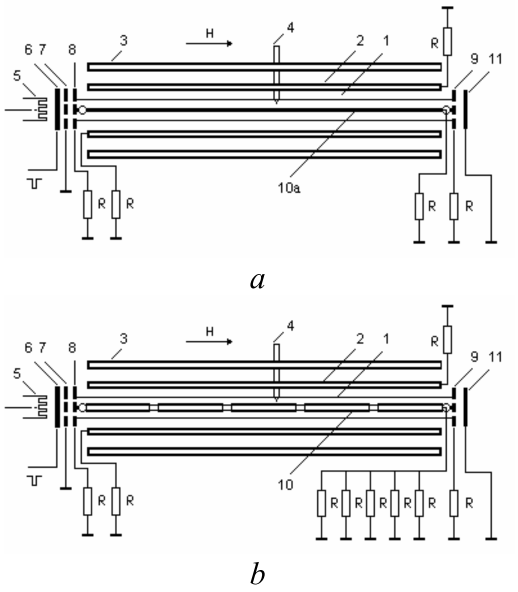

Fig. 1. The scheme of experimental setup:
a - modification with an axial electrode as a metal string,.
b - modification with an axial multielement electrode

Diagnostic measurements of axial distribution of electrostatic potential were made by high-frequency Langmuir probe 4. 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.

3. EXPERIMENTAL RESULTS

3.1. STUDIES WITH A SINGLE AXIAL ELECTRODE

Fig. 2. presents the injection current pulses observed on the entrance grid of the drift tube, fluctuations registered by π-electrodes, negative polarity voltage pulses applied to the central electrode. Experiment was carried out in the following way. The negative polarity voltage pulse with the amplitude u_1 = -20 V was applied to the central electrode at the same time with the beam injection pulse.

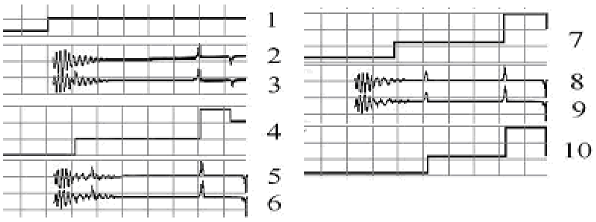

Fig.2. The oscillograms of current I_{in} on the entrance grid (1), current I_1 and I_2 on π-electrodes (2, 3, 5, 6, 8, 9) and negative pulses on the central electrode (4, 7, 10):
4 -τ_1 = 0.6ms, u_1 = -20 V, τ_2 = 1.0 ms, u_2 = -14 V, τ_3 = 0.25 ms, u_3 = 0 V;
7 -τ_1 = 0.75 ms, u_1 =-20 V, τ_2 = 0.85 ms, u_2 =-14 V, τ_3 = 0.4 ms, u_3 = 0 V;
10 - τ_1 = 0.6 ms, u_1 =-20 V, τ_2 = 1.0 ms, u_2 =-14 V, τ_3 = 0.25 ms, u_3 = 0 V;
Broach – 0.2 ms/point; sensitivity – 0.01 V / point (2, 3, 5, 6, 8, 9), 10 V/point (4, 7, 10)

After the ending injection pulse the central electrode voltage was supported on the certain level u_1 during the time period τ_1. Then during the time period much shorter than diocotron oscillation period it was changed up to value u_2 = -14 V and was supported at this value during time period τ_2. After that the voltage value was changed to zero during the time period τ. In this experiment the sum $\tau_1 + \tau_2$ was constant. The basic idea of such form of pulse using consists in control of accumulated electrons motion conditions.

From fig.2. one could determine, that the negative pulse amplitude variation from u_1 up to u_2 results in the diocotron oscillations frequency decreasing. Also it displays the fact of next relation existence $u_2/u_1 \approx \omega_2/\omega_1$ in the wide range of τ_1, τ_2 values. Here ω_1 and ω_2 are the diocotron oscillation frequencies corresponding to central electrode voltage pulse amplitudes u_1 and u_2. After the 0.6 ms delay on the injection pulse ending the voltage pulse amplitude jump from u_1 up to u_2 excites a new diocotron instability. This testifies that the electron lifetime estimation provided by measuring the diocotron oscillations damping length was detracted.

Fig. 2. shows the injection current pulses observed on the entrance grid of the drift tube, fluctuations registered by π-electrodes, different polarity voltage pulses applied to the central electrode. The negative polarity pulse with amplitude u_1 =-10 V was applied to the central electrode at the same time with the beam injection pulse. Then during the time period much shorter than diocotron oscillation period it was changed up to value u_2 =+20 V. After the ending injection pulse the central electrode voltage was supported on the certain level u_1 during the time period τ_3. After that it was rapidly declined to the value u_3 = -20 V. In this experiment the sum $\tau_1 + \tau_2 + \tau_3$ was constant.

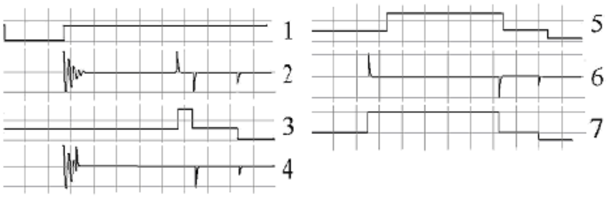

Fig.3. The oscillograms of current I_{in} on an entrance grid (1), of current on a π-electrode (2, 4, 6) and of various polarity pulses on the central electrode (3, 5, 7):
3 - τ_1 = 1.8 ms, u_1 = -10 V, τ_2 = 0.12 ms, u_2 = +20V, τ_3 = 0.25 ms, u_3 = -20 V;
5 - τ_1 = 1.8 ms, u_1 =-10 V, τ_2 = 0.9 ms, u_2 =+20 V, τ_3 = 0.25 ms, u_3 = -20 V;
7 - τ_1 = 1.8 ms, u_1 =-10 V, τ_2 = 1.0 ms, u_2 =+20 V, τ_3 = 0.25 ms, u_3 =-20 V;
Broach – 0.2 ms/point; sensitivity – 0.01 V / point (2, 4, 6), 10 V/point (3, 5, 7)

From fig.3. one could observe that the presence of positive polarity voltage pulse on the central electrode does not excite the diocotron instability. And the variation of the pulse duration does not affect on the qualitative picture of observed phenomena. Thus one could conclude that the appliance of positive polarity voltage pulse suppresses the diocotron instability.

3.2. STUDIES WITH A MULTIELEMENT AXIAL ELECTRODE

The experimental study was provided for two regimes of setup operation:

- positive polarity voltage pulse was applied to the axial electrode element 3 with the certain delay after injection beginning. Other elements were grounded through the certain resistance (fig. 4a);
- positive polarity potential was applied to the axial electrode elements 2 and 4. Other elements were grounded (fig. 4b).

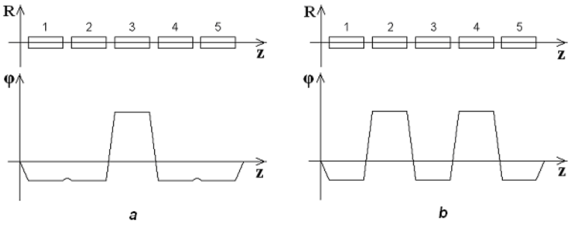

Fig. 4. The distributions of potential on the axial electrode elements

The signal was obtained from π-electrodes using oscillograph. The oscillograms were similar to displayed on fig.5 for both of observed regimes. The oscillations detected by π-electrodes were antiphased. Together with the fact of oscillations frequency dependence on the magnetic and electric field intensities, this fact allows to conclude that these oscillations have a diocotron character in a mode with l=1.

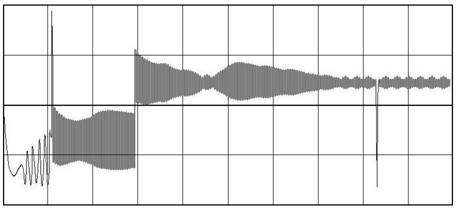

Fig. 5. The diocotron oscillations on π -electrodes at submission of positive polarity voltage pulse on the axial electrode element. Broach - 1 ms/point, sensitivity - 0.01 V/point

Fig.5 displays that the diocotron oscillations are excited by the main pulse. The appliance of long duration additional positive polarity pulse on the axial electrode elements results in the diocotron frequency increasing which corresponds to a particles density increasing. The oscillations frequency varies poorly during the whole pulse. Also during this pulse the amplitude modulation was observed. After the end of stimulation pulse the diocotron oscillations frequency and amplitude damps very slowly. This testifies that confined electrons are rather cold and after the stimulating pulse termination they spread slowly along the magnetic field.

Given configuration of charged particles drift differs from one with a single electrode and allows confining electrons for a much longer time period.

CONCLUSIONS

The experimental study of electron dynamics in the drift space with the presence of central electrode allows concluding:

- single axial electrode configuration utilization allows to suppress the diocotron instability due to influence of cross electric field;
- self-consistent electron confinement in the space of drift may be stimulated using the axis electrode configuration;
- the application of multielement axial electrode allows to accumulate and confine electrons in drift space for a long enough time period.

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НАКОПЛЕНИЕ И УДЕРЖАНИЕ ЭЛЕКТРОНОВ В ЛОВУШКЕ ПЕННИНГА С ЦЕНТРАЛЬНЫМ ЭЛЕКТРОДОМ

С.Н. Маньковский, Д.А. Ситников, И.К. Тарасов, И.В. Ткаченко, В.И. Ткаченко

Представлены результаты теоретического и экспериментального исследования накопления электронов при инжекции сильно размытого по скоростям трубчатого пучка электронов в ловушку Пеннинга в присутствии центрального электрода.

НАКОПИЧЕННЯ ТА УТРИМАННЯ ЕЛЕКТРОНІВ У ПАСТЦІ ПЕННІНГА З ЦЕНТРАЛЬНИМ ЕЛЕКТРОДОМ

С.М. Маньковський, Д.А. Ситников, І.К. Тарасов, І.В. Ткаченко, В.І. Ткаченко

Представлено результати теоретичного та експериментального дослідження накопичення електронів протягом інжекції розмитого по швидкостях трубчатого пучка електронів у пастку Пеннінга за присутності центрального електроду.