SEPARATION ON VELOCITIES OF THE PARTICLES TRAPPED IN SELF-CONSISTENT MALMBERG-PENNING TRAP

I.K.Tarasov, V.I. Maslov, M.I.Tarasov*, E.D.Volkov

NSC Kharkov Institute of Physics and Technology, Kharkov, Ukraine;
****V.N. Karazin Kharkov National University, Kharkov, 61108, Ukraine;***
E-mail: itarasov@ipp.kharkov.ua

Coherent structures and conditions of their occurrence in holding configurations have recently attracted the attention of many physicists working on nuclear fusion and nonlinear processes in plasma. Here we discuss the mechanisms of cooling of the electron plasma seized in the self-consistent electromagnetic trap.

PACS: 52.27.Jt

INTRODUCTION

The mechanism of the trapped electron cooling, during their drift in the dynamic trap, is investigated experimentally and theoretically. The particle separation by velocities occurs both at the stage of trapping and during the confinement of electrons by the electric and magnetic fields. At the stage of trapping, the mechanism of the electron separation by the energy depends on the value of the potential barrier. For the trapped particles drifting in crossed electrical and magnetic fields for a long time the cooling is achieved due to the diffusion of the fast particles on the wall of the drift chamber. Thus optimization of the electron beam arrangement in relation to the wall of the drift chamber is necessary. Interestingly the instabilities that develop in the drifting stream of the non-neutral? particles promote increase of the diffusion across the magnetic field.

We previously described the experimental data and mathematical models of formation? of a self-consistent traps such as Malmberg – Penning traps [1,2].

EXPERIMENTAL RESULTS

The experimental setup is described in [3]. The breakdown of the current transported through the drift space of a 'hot' beam was observed when the current had exceeded some threshold value [4]. The output of particles was observed during the pulse of injection with occurrence of sagging of the potential in the drift space of the non-neutral? particles. The stream of electrons flowing through the drift space is strongly heterogeneous?? by the velocity and the cross-section drift radius (with the account of Larmor radius) is proportional to the energy of the particles. In this case the fastest particles contact the conducting holding wall the first. Loss of fast particles from the holding configuration is equivalent to the group cooling of the confined particles.

We investigated the dependence of particles lifetime after the end of the pulse of injection, ,"time of afterglow", on the injection conditions, presence of instabilities and their amplitudes down to a nonlinear progress stage.

In Fig.1 the dependence of the particles lifetime on the distance between the stream and the walls of drift chamber is presented. The distance was varied by changing the value of the holding magnetic field, the distance was measured by lateral Langmuir probe moving in a radial direction. Figure shows, that there is an optimal distance from walls of the drift chamber for maximal lifetime of the particles in the mode of "afterglow".

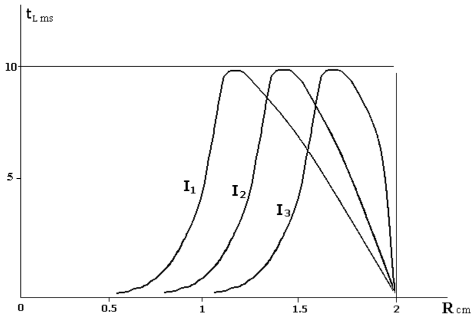

Fig. 1. Dependence of the particles lifetime on the beam radius in the drift tube

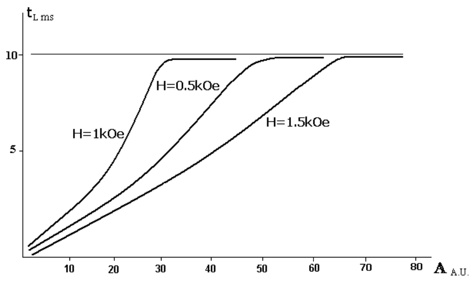

Fig. 2. Dependence of the particles lifetime on the value of the diocotron oscillations amplitude

The family of dependences of the particles lifetime on the amplitude of the diocotron oscillations (that always accompany the flow of the particles through the drift space) is given in Fig. 2. These oscillations had coherent character and were concentrated in the confinement area. The lifetime value of 10 ms undertakes as calibrate time, and the absolute lifetime can be significantly larger.

Dependence of the particles lifetimes on the injection pulse duration value is presented in Fig. 3. The figure shows that the loss of energy by particles begins at pulse duration not less ~ 500 µs (as well as coherent diocotron oscillations) and increases with duration of the pulse of injection up to saturation at duration ~1.2 ms.

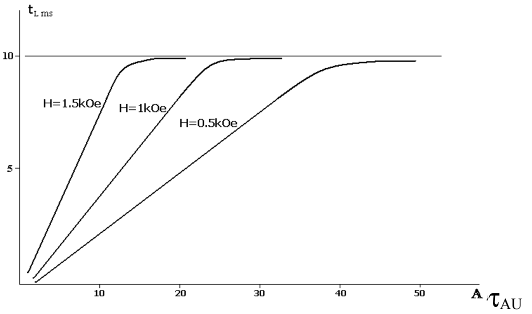

Fig. 3. Dependence of the particle lifetime on the injection pulse duration

In Fig. 4, the dependence of the particles lifetime ?????at the nonlinear stage of diocotron oscillations, displayed as modulation instabilities of diocotron oscillations???????? on the amplitude of modulation of the diocotron oscillations and its frequency is given. The particles lifetime in the mode of "afterglow" grows with growth of modulation parameters (frequency, amplitude) until the transition of the oscillations into a stochastic mode.

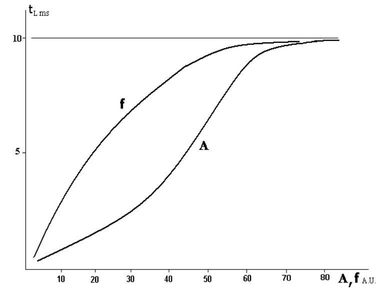

Fig. 4. Dependence of the particles lifetime on the diocotron oscillations modulation amplitude and frequency

This emission is followed by throwing of the beam on smaller radius of drift. In Fig. 5, the distribution functions f(U) are presented for the injected beam that past in the drift interval are submitted curve - 70 cm. The figure shows, that, in the space of drift, strongly heterogeneous by velocity??? electron beam have variation in the longitudinal speed ,d??V comparable with drift speed, V_{dr} is injected. The ratio V/V_{dr} measured on half height of ordinate f(U) for curve 1 is :V/V_{dr}= 0.8.

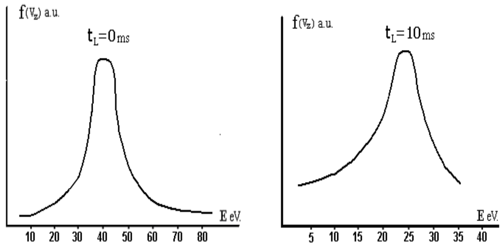

Fig. 5. Transformation of the particles distribution on velocity function (with particles cooling)

The beam that has passed through the drift space remains scattered and the number of particles with low velocities increases. Thus, the transformation of distribution function takes place, which corresponds to localization of the self- consistent electromagnetic trap in the drift space and to the conditions of such trap occurrence.

FALL ON THE WALL OR SHIFT TO THE AXIS IN DEPENDENCE ON THE PHASE OF THE EXCITED FIELD

For the description of the electron dynamics we use the equations

$$\frac{\partial \vec{V}}{\partial t}+\left(\vec{V}\vec{\nabla}\right)\vec{V}=\left(\frac{e}{m_e}\right)\vec{\nabla}\phi+\left[\vec{\omega}_{He},\,\vec{V}\right], \qquad (1)$$

$$\vec{V}=-\left(\frac{e}{m_e\omega_{He}}\right)\left[\vec{e}_z,\,E_{ro}\right]+\left(\frac{e}{m_e\omega_{He}}\right)\left[\vec{e}_z,\,\vec{\nabla}\varphi\right]-$$
$$-\frac{1}{\omega_{He}}\partial_t\left[\vec{e}_z,\,\vec{V}\right]-\frac{1}{\omega_{He}}\left[\vec{e}_z,\,\left(\vec{V}\vec{\nabla}\right)\vec{V}\right]$$
$$, \qquad (2)$$

$$\vec{\nabla}\phi\equiv\vec{\nabla}\varphi-E_{ro}\,. \qquad (3)$$

One can present

$$\vec{V}=\vec{V}_{\theta o}+\delta\vec{V}\,. \qquad (4)$$

In zero approximation from (2) we find [5]:

$$V_{\theta o}=-\frac{eE_{ro}}{m_e\omega_{He}}-\frac{V_{\theta o}^2}{r\omega_{He}}\,. \qquad (5)$$

From here

$$V_{\theta o}=\frac{r\omega_{He}}{2}-\sqrt{\left(\frac{r\omega_{He}}{2}\right)^2-\frac{erE_{ro}}{m_e}}\,. \qquad (6)$$

At

$$\eta\equiv\frac{4\,eE_{ro}}{rm_e\omega_{He}^2}<<1 \qquad (7)$$

$$V_{\theta o}\approx\frac{eE_{ro}}{m_e\omega_{He}}\,. \qquad (8)$$

We search

$$\delta \vec{V} = \delta \vec{V}\left(t,\ \theta - \omega_{ph} t\right) . \qquad (9)$$

Then representing

$$\frac{\partial \delta \vec{V}}{\partial t} = \gamma \delta \vec{V} - \left(\omega_{ph} \partial_{\theta}\right) \delta \vec{V} \ , \qquad (10)$$

we derive:

$$\delta \vec{V} = + \left(\frac{e}{m_e \omega_{He}}\right)\left[\vec{e}_z,\ \vec{\nabla}\varphi\right] - $$

$$- \frac{1}{\omega_{He}}\left(\left[\vec{e}_z,\ \left(V_{\theta o} - V_{ph}\right)\nabla_{\theta} \delta \vec{V}\right]\right) - \frac{1}{\omega_{He}}\gamma\left[\vec{e}_z,\ \delta \right. \qquad (11)$$

First two members?? in the right part of (12) describe periodic electron fluctuations in the field of the quasistationary vortex $\delta \vec{V}^{(1)}$, and the third member describes the radial electron fall on a cylindrical wall and their shift to the axis $\delta \vec{V}^{(2)}$

$$\delta V_r^{(2)} = \frac{\gamma \delta V_{\theta}^{(1)}}{\omega_{He}} \approx \frac{\gamma\left(V_{\theta o} - V_{ph}\right)}{\omega_{He}} , \qquad (12)$$

Since at diocotron instability the parameter $\frac{\gamma}{\omega_{He}}$ is not small, the radial electron separation is essential. Thus, as the angular moment is proportional to r^2 , according to the balance of the moments of the pulses at fall on a wall of an electron part the other electron are shifted to the axis.

CONCLUSIONS

Electrons cool due to the emission of the fastest particles on the drift chamber wall. Accumulation of particles on walls can occur during drift of the non neutral?? plasma in the crossed fields, and due to the development of instability based on the particles drift (diocotron instability). This results in redistribution of particles by radius and by azimuth in the space of drift.

At a nonlinear stage diocotron instability, there is most active emission of fast particles in radial direction with the loss of temperature of the particles remaining in a trap.

REFERENCES

1. J.H. Malmberg and C.F. Driscoll. Long-Time Containment of Pure Electron Plasma // *Phys. Rev. Lett.* 1980, v.44, No.10, p.654-657.

2. X.P. Huang, F. Anderegs, E.M. Hollmann, C.F.Driscoll and T.M. O'Neil. Steady-State Confinement of Non-neutral Plasmas by Rotating Electric Fields // *Phys. Rev. Lett.* 1997, v.78, No.5, p.875-878.

3. A.A. Buzyukov, E.D. Volkov, I.K. Tarasov // *Problems of atomic science and technology. Series: Plasma Physics (7).* 2002, No.4, p.146-148.

4. V.A. Bashko, S.M. Krivoruchko, and I.K. Tarasov // *16 th Europ. Conf. on Contr. Fusion and Plasma Phys.*, Venice, 1989, v.13B, part IV, p.1587.

5. R.C. Davidson. *Theory of nonneutral plasmas.* London-Amsterdam. 1974.

СЕПАРАЦИЯ ПО СКОРОСТЯМ ЧАСТИЦ, ЗАХВАЧЕННЫХ В САМОСОГЛАСОВАННУЮ ЛОВУШКУ МАЛМБЕРГА-ПЕННИНГА

И.К. Тарасов, В.И. Маслов, М.И. Тарасов, Е.Д. Волков

Когерентные структуры и условия их возникновения в удерживающей конфигурации в последнее время привлекли внимание физиков работающих в области исследования термоядерного синтеза и нелинейных процессов в плазме. Рассмотрены результаты исследований механизмов охлаждения электронной плазмы, захваченной в самосогласованную электромагнитную ловушку.

СЕПАРАЦІЯ ПО ШВИДКОСТЯХ ЧАСТОК, ЗАХОПЛЕНИХ У САМОУЗГОДЖЕНУ ПАСТКУ МАЛМБЕРГА-ПЕННІНГА

І.К. Тарасов, В.І. Маслов, М.І. Тарасов, Є.Д. Волков

Когерентні структури й умови їх виникнення в утримуючій конфігурації останнім часом звернули на себе увагу фізиків, працюючих в області дослідження термоядерного синтезу та нелілійних процесів у плазмі. Розглянуто результати досліджень механізмів охолодження електронної плазми, захопленої у самоузгоджену пастку.

Господа, вы перечитываете перевод? Не забывайте, что он ДОЛЖЕН иметь СМЫСЛ сам по себе, т.е. без русской версии, иначе зачем вообще что-то переводить? Важен ведь БЭКГРАУНД модели, а не уры.