FORMATION AND PROPERTIES OF SELF-CONSISTENT MALMBERG-PENNING TRAP

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In recent years a big attention is given to coherent structures at an explanation of phenomena of the fast convective carry from the scratch-off-layer in devices such as “tokamak” and “stellarator”. Coherent structures can appear at occurrence of the self-consistent electromagnetic traps (similar to Malmberg-Penning trap) with confinement and cooling of charged plasma in them. In this paper the results of researches of an opportunity of the self-consistent confinement configuration formation in the non-neutral plasma represented.
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INTRODUCTION

The excitation and properties of electric trap for beam’s electrons, which move through a metallic tube, are investigated theoretically and experimentally in this paper. The electron beam is shown to provide the instability development. The instability leads to the formation of the non-stationary electric barrier and the appearance of electric potential trap. This phenomenon is observed in the central region of the tube, where the hump of the electric potential is formed [4]. On the end of the cylinder two dips of the electric potential are formed. The trap confines electrons during the barrier formation and keeps them inside the drift tube. Trapped electrons have low temperature and are unstable concerning the diocotron instability development. During the diocotron instability development the spatial charge redistribution takes place in the beam cross-section, which is connected with the electron drift in longitudinal magnetic and radial electric fields [1,2].

EXPERIMENTAL RESULTS

The experimental setup is shown in [3].

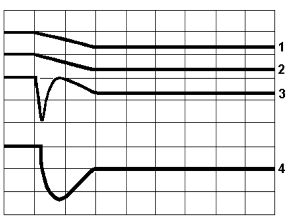

Fig.1.Oscillogrammes: 1 – impulse voltage on the cathode, 2 - current on the input grid, 3 - current on the output grid, 4 - currents on π - electrodes. U_B = 30 V, scale - 2 μs/div, sensitivity 1 - 5 mA/div, 2 - 1.2 mA/div, 3 - 0.25 mA/div, 4 - 4.5 μA/div

During the experiments a number of phenomena was observed similar to the processes accompanying the well-known phenomenon of current breakdown during the propagation of a monopower electron beam in vacuum [3]. Fig. 1 represents the oscillogrammes: of the negative pulse of the voltage on the cathode of the electron gun - 1; the injected current I_{in} - 2; the current that passed through the drift space I_{out} – 3; the radial currents -4. The averaged by time (time of averaging - 20 s) distribution function of the particles by the longitudinal speeds was measured using of mobile electrostatic analyzer.

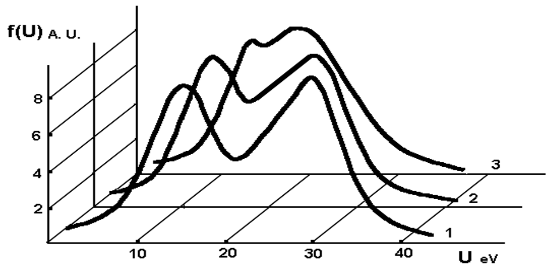

Fig. 2. The function of electron beam distribution on speeds in three points along a magnetic field. U_B = 30 B, I_B = 17mA, H = 1 kOe. 1 - Z = 10 cm, 2 - Z = 40 cm, 3 - Z = 70 cm, I_B = 17 мА

On Fig. 2 the distribution functions f(U) are presented for the injected beam that past in the drift interval are submitted: curve 1 - 10 cm, curve 2 - 40 cm, curve 3 - 70 cm. The figure shows us, that in space of drift strongly dim on speeds electron beam have disorder on longitudinal speed V, comparable with drift speed V_{dr} is injected . The division V / V_{dr}, is measured on halfheigh of ordinate f (U) for curve 1 is V / V_{dr} = 0.8. The beam that has passed through the drift interval remains scattering and the amount of particles with low velocities increases. A reorganization of function of distribution takes place, when the electron beam passes through the drift space. With two maxima-shape in the initial area of the drift space, the distribution function gets one-maximum shape when moving from the injection plane to the central intermediate region of the drift space. It is necessary to note, that after being injected into the drift channel the electron beam loses its energy at about 10-20 eV. The distribution function of the particles by velocity has a two-maxima shape when the emission current reaches 10 mA. The distribution of

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the electric potential in the drift space during the impulse of injection was obtained by measuring the floating potential in the axial direction with electrostatic probe.

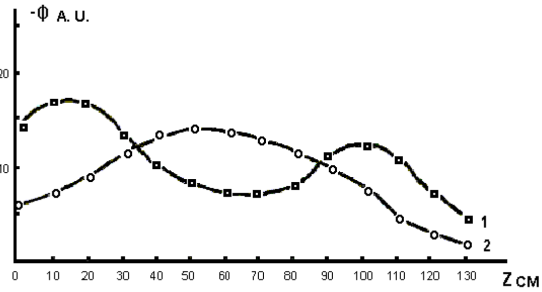

Fig.3. Distribution of the potential in the axial direction of the drift space. U_B = 30 V, H = 1 kOe, 1 – I_B = 17 mA, 2 – I_B = 10 mA

In Fig.3 the dependences of the distribution of plasma potential in the drift space along the magnetic field are given. The curve 1 corresponds to the intensity of the magnetic field 1 kOe and the duration of the pulse of injection - 5 μs. The current of injection of the electron beam was 17 mA. The curve 2 corresponds to the intensity of the magnetic field 1 kOe, and the current of injection 10 mA The behaviour of the curves in Fig. 3. demonstrates that in the central part of the drift space, depending on the current of injection, there exist regions with the increased potential. The spatial distribution of the potential depends on the energy of injection U_i (the potential increases with the energy increase) and on the intensity of magnetic field. The injection current being changed, the form of the spatial distribution changes as well, instead of one maximum it gets two maxima with 70-90 cm between them. It takes no more than 10 ms for the system to make such transition.

DIOCOTRON INSTABILITY DEVELOPMENT AT FINITE LONGITUDINAL WAVEVECTOR

Let's consider the development of the diocotron instability at a finite longitudinal wave vector k_z of the cylindrical electron beam with the internal R_o and external R_p radiuses, moving with velocity V_o inside the magnetized metal cylinder with radius R_c and length L . We take into account members not more senior than the first degree k_z . Also we neglect cross members $\frac{k_z}{\omega_c}$. We take into account members not more senior than the first degree on $\frac{\omega_p}{\omega_c}$. Here ω_p , ω_c are the electron plasma and cyclotron frequencies. We use the following equations [5]

$$r^{-1}\partial_r r\,\partial_r \varphi - \frac{\ell^2}{r^2}\varphi = 0\ ,\ r \neq R_o,\ R_p \quad (1)$$

Here φ is the electric potential.

$$\varphi_1 = \beta r^{\ell} + \frac{\chi}{r^{\ell}}\ ,\ R_o < r < R_p$$

$$\varphi_2 = \left(\beta + \frac{\chi}{R_o^{2\ell}}\right) r^{\ell}\ ,\ 0 < r < R_o \quad (2)$$

$$\varphi_3 = \left(\beta R_p^{2\ell} + \chi\right)\frac{R_c^{2\ell} - r^{2\ell}}{R_c^{2\ell} - R_p^{2\ell}}\frac{1}{r^{\ell}}\ ,\ R_p < r < R_c$$

$$r^{-1}\partial_r r\,\partial_r \varphi - \frac{\ell^2}{r^2}\varphi = -\frac{\ell}{\omega_c r}\frac{\varphi\,\partial_r \omega_p^2}{\left(\omega - \ell\omega_e - k_z V_o\right)} \quad (3)$$

From (3) for $r = R_o,\ R_p$ we derive

$$R_p\left(\varphi_3 - \varphi_2\right)\big|_{r=R_p} = \frac{\ell}{\omega_c}\frac{\varphi\big|_{r=R_p}\omega_p^2}{\left(\omega - \ell\omega_e\left(R_p\right) - k_z V_o\right)}$$

$$R_o\left(\varphi_2 - \varphi_1\right)\big|_{r=R_o} = -\frac{\ell}{\omega_c}\frac{\varphi\big|_{r=R_o}\omega_p^2}{\left(\omega - \ell\omega_e\left(R_o\right) - k_z V_o\right)} \quad (4)$$

Here $\omega_e\left(R_p\right) = \omega_d\left(1 - \frac{R_o^2}{R_p^2}\right)$, $\omega_e\left(R_o\right) = 0$, $\omega_d = \frac{\omega_p^2}{2\omega_c}$, ω is the perturbation frequency. From (2)-(4) it follows

$$\frac{\left(\omega - k_z V_o\right)^2}{\omega_d^2} - \alpha_1\frac{\left(\omega - k_z V_o\right)}{\omega_d} + \alpha_2 = 0 \quad (5)$$

Here $\alpha_1 = \ell\left(1 - \frac{R_o^2}{R_p^2}\right) + \left(\frac{R_p^{2\ell}}{R_c^{2\ell}} - \frac{R_o^{2\ell}}{R_c^{2\ell}}\right)$,

$$\alpha_2 = \ell\left(1 - \frac{R_o^2}{R_p^2}\right)\left(1 - \frac{R_o^{2\ell}}{R_c^{2\ell}}\right) - \left(1 - \frac{R_o^{2\ell}}{R_p^{2\ell}}\right)\left(1 - \frac{R_p^{2\ell}}{R_c^{2\ell}}\right)$$

. The solution (5) looks like $\omega = \mathrm{Re}\,\omega + i\,\mathrm{Im}\,\omega$

$$\mathrm{Re}\,\omega = k_z V_o + \frac{\alpha_1\omega_d}{2}\ ,$$

$$\mathrm{Im}\,\omega = \frac{\omega_d}{2}\sqrt{4\alpha_2 - \alpha_1^2} \quad (6)$$

If $k_z = -\frac{\alpha_1\omega_d}{2V_o}$, the perturbation does not move in the longitudinal direction. The comparison with the experimental data shows, that $\lambda = \frac{2\pi}{k_z} = \frac{4\pi V_o}{\alpha_1\omega_d} \approx L$ the length of the perturbation is approximately equal to the system length.

From the given parameters:
ω_p=2/3×10[8]radn/sec, ω_c=2×10[9]radn/sec, R_0=12mm., R_p=15mm., R_c=20mm., V_0=0,5×10[7]cm/sec.we obtain:
α_1=0.5625, ω_d=1/9×10[7]Hz.
Then we find λ=113.04cm. Which has same order with the device length L=150cm.

CONCLUSIONS

The results obtained lead to the following conclusions. Upon the injection of an electron beam with a broad velocity distribution into the drift space with a longitudinal magnetic field the majority of the particles experiences a reorganization of their movement: they start moving in the azimuthal direction, having lost their axial velocity Such reorganization promotes the occurrence of sagging of the spatial potential and a virtual cathode as a consequence, thus changing the dynamics of particles particles in drift space. An inverse flow of the electrons takes place and a certain part of particles leave in a radial direction.The inverse flow performs a transformation of the function of distribution, so it gets the second maximum, and the loss of the electrons in the radial direction causes a non-stationarity of the virtual cathode and following increase of passing current. As a result, during the time corresponding to the front of increase of the current of injection, between two saggings of the potential a dynamic trap is formed that can capture 'slow' electrons that are situated in the drift space upon the occurrence of double sagging.

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ФОРМИРОВАНИЕ И СВОЙСТВА САМОСОГЛАСОВАННОЙ ЛОВУШКИ МАЛМБЕРГА-ПЕННИНГА

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В последнее время большое внимание уделяется когерентным структурам в связи с объяснением явления быстрого конвективного переноса из области обдирки в установках типа «токамак» и «стелларатор». Когерентные структуры могут возникать в самосогласованных электромагнитных ловушках (подобных ловушкам Малмберга Пеннинга) при удержании и охлаждении заряженной плазмы в них. В работе представлены результаты исследования возможности формирования конфигурации самосогласованного удержания в заряженной плазме.

ФОРМУВАННЯ ТА ВЛАСТИВОСТІ САМОУЗГОДЖЕННОЇ ПАСТКИ МАЛМБЕРГА-ПЕННІНГА

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Останнім часом багато уваги приділяється когерентним структурам у зв’язку з поясненням явища швидкого конвективного переносу з області обдирки в установках типу „токамак” та „стеларатор”. Когерентні структури можуть виникати у самоузгоджених електромагнітних пастках (подібних до пасток Малмберга-Пеннінга) при наявності утримання та охолодження в них зарядженної плазми. У работі представлено результати досліджень щодо можливості формування конфігурації самоузгодженного утримання у заряджeній плазмі.