UDC 533.9

MECHANISM OF ELECTRIC POTENTIAL TRAP FORMATION DUE TO INJECT OF ELECTRON BEAM INTO A UNIFORM MAGNETIC FIELD

A.A. Bizyukov[1], E.D. Volkov[2], I.K. Tarasov[2]

[1] - Kharkov National University, Kurchatov Ave. 31, 61108, Kharkov, Ukraine. [2] - Institute of Plasma physics, NSC «Kharkov Institute of Physics and Technology», Academicheskaya Str. 1, 61108, Kharkov, Ukraine. itarasov@ipp.kharkov.ua

INTRODUCTION

The mechanism of non-neutral electron plasma accumulation and confinement during injection of widely spread in longitudinal velocity electron beam into a drift tube in a strong uniform magnetic field was studied experimentally. The properties and the formation of collective electron trap for electron beam that propagates in conducting cylinder are described in this paper. It is shown that the electron beam provides the development of an instability in the above mentioned conditions. The instability leads to the formation of electric potential trap. The trap captures electrons during the formation and keeps them inside the drift tube.

EXPERIMENTAL RESULTS

A detiled describtion of the experimental setup is given in [6].

In this section we present experimental results on the buildup and confinement of electrons during injection of a beam with a velocity spread. The beam operated in the pulsed mode with a current pulse length of 0.1 - 100 ms.

In the experiments performed, special attention was devoted to analyzing the ion background influence, the background having being by beam electron ionizing the residual gas.In our experiments this influence of ion background with ionizing the residual gas by beam electrons was not essential.

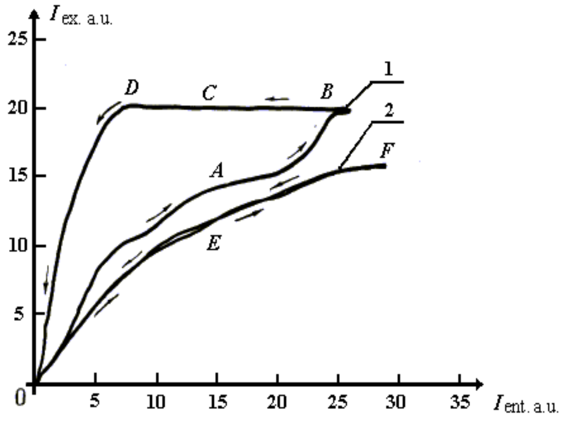

Fig.1 The dependence of the current I_{EX} versus I_{ENT} for the pulsed beam U_B=50B, t - pulse duration, T - time between the pulse 1 - t=400 ms, Ò=800 ms, 2 - t=400 ms, Ò=2.8 ì s

In Fig.1 there are depicted the dependence of the current passed through the drift space I_{EX} versus the current at the entrance I_{ENT} when the voltage at the electron gun cathode is U=-50V. It is seen from Fig.2 that with I_{ENT} increasing the movement along the curve 1 from the point 0 to point B is accomplished along its lower branch. When I_{ENT} decreases, the movement along the curve from B to O is along its upper branch. Thus, curve 1 exhibits a hysteresis on I_{EX} versus $\mathrm{I}_{\mathrm{ENT}}$ dependence which, however, is opposite in nature to the well-known similar hysteresis dependence for the monoenergetic beam and the beam having a strong spread over longitudinal velocities [1]when they work in the stationary regime. Meanwhile, in curve 2 on Fig.1 the hysteresis in I_{EX} versus I_{ENT} dependence is absent. Curve 2 differs from curve 1 in this figure only in the delay time between two subsequent periodic current pulses. This time is 3.5 times larger in curve 2 as compared with curve 1. The different behaviour of curves 1 and 2 in Fig.1 points to the presence of the noticeable volume charge in the drift space even after switching off of the beam injection pulse. Indeed, only the presence of trapped electrons which drift comparatively long time in the magnetic field and the effect of which is essential 400 µs after the injection pulse ended may explain the reverse hysteresis on I_{EX} versus I_{ENT} dependence, curve 1 in Fig.1 When the beam of 400 µs duration with 400 µs pause between pulses is injected, the drift space has no time to free itself from the space charge accumulated during the previous currente pulse.

Figure 2 shows oscilloscope traces of the current pulse I_{ENT} on the entrance grid (1) and of the currents I_1 and I_2 on the π-electrodes for various beam pulse lengths (2-7). It is clear that when the constant current (trace 1) is injected into the drift space of the beam, except for a negative current pulse at the time of injection, the induced periodic signal is detected on the π-electrodes both while the pulse is being injected and afterward (traces 2, 3, 6, 7). The periodic current oscillations which are symmetric with respect to the mean value during the injection of the pulse and are symmetric about zero after the pulse is finished, arise due to the periodic polarization of the π-electrodes by space charge. It can also be seen that during injection the periodic oscillations do not develop right behind the leading edge, but after a time τ . This time delay depends on the value $\mathrm{I}_{\mathrm{ENT}}$ of the injected current, the magnetic field H, and the beam energy u, and has a scale of µs. The oscillations detected by the π-electrodes have the following properties: low frequency oscillations of the current I_1 and I_2 are always excited simultaneously but 180° out of phase with one another; the frequency of these oscillations $\omega_{d,}$ is always larger during the pulse than the oscillations frequency of the "tail" which breaks up after shuts off; and the minimum injection pulse length $T_{\min}$ at which oscillations of the "tail" are observed is equal to the delay time τ, i, e., we have $T_{\min}$ τ (traces 4 and 5) . When the current pulse length T increases, the tail and oscillation frequencies in it last for a longer time. At some value $T=T_{\max}$ observe stabilization of tail , which means that increasing the temperature, $T>T_{\max}$, does not increase the frequency or the overall duration of the oscillations. The oscillation frequency w_d is inversely proportional to the magnetic field strength when the latter varies over the range H=100-1500 G. As the tail decays its oscillation frequency ω_d always decreases. It is especially noteworthy that low-frequency oscillations ω_d are excited under conditions such that high-frequency density and potential fluctuations in the range of the frequencies ω_{pe} and ω_{he} nonneutral particles oscillations in the drive space have diocotrone nature.

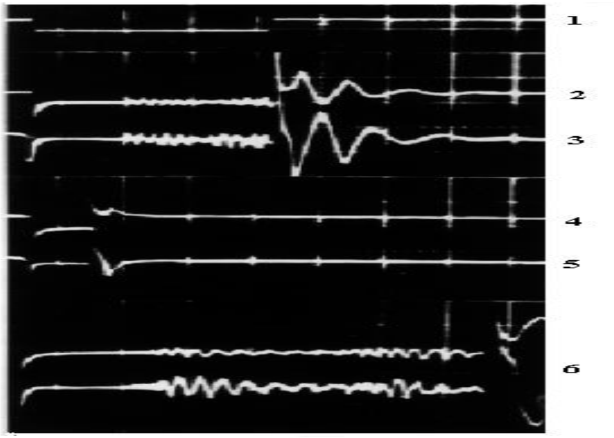

Fig.2. Oscilloscope traces of the current I_{ENT} at the entrance grid (1) and of the currents I_1 and I_2 on the p-electrodes for an injection current pulse of length T=0.37 ms (2,3), T=0.1 ms (4,5), T= ms with a scale of 0.05 ms / div (6, 7). For traces 1 -5 the scale is 0.1 ms/div. The sensitivity on the ordinate is 5×10^{-3} A/div (1) and 2×10^{-6} A/div (2-7).

Figure 3 shows oscilloscope traces of oscillations of the accumulated nonneutral plasma, detected by the π-electrodes when the auxiliary beam acts on it. The pulse length of the auxiliary beam is shorter by a factor of five than that of the main beam and is equal to 250μs. This pulse length was chosen for the auxiliary beam with the idea of avoiding any buildup of electrons in the drift tube when no particles are present after the accumulated electrons have disappeared. Oscilloscope traces 1 and 2 of Fig. 3 show that these conditions have been satisfied. It is evident that when the onset of the auxiliary beam is delayed by τ=1.6 ms relative to the end of the main beams the drift tube succeeds in getting rid of the accumulated plasma , and the π-electrodes detect almost identical damped oscillation "tails" in the l=1 mode, 180° out of phase. A small part of the auxiliary beam current (two pulses of negative polarity) is collected by them. When the delay is reduced to τ=1.2 ms (Fig. 4 , trace 3) , we see that the auxiliary beam has a substantial effect on the accumulated plasma. The most important thing is that the tail of the oscillations is extended to 1.9 ms, which is 0.5 ms longer than in the case shown by traces 1 and 2 in Fig. 3. It is also clear that the waves are damped while the beam is being injected over a time corresponding to 4-5 oscillations of the l=1 mode. At the same time the oscillation frequency increases by 20-25%. As the delay time τ decreases (trace 4 and 5 in Fig. 2) the wave damping time increases: now it amounts to 2-3 periods of the l=1 mode, while the duration of the oscillatory tail with a delay of τ=0.2 ms is about 0.2 ms longer for trace 5 than for traces 1 and 2. Thus, injecting the auxiliary beam increases the lifetime of the accumulated plasma and also slows down the rate at which the precession of the collection of electrons about its axis of symmetry damps away .

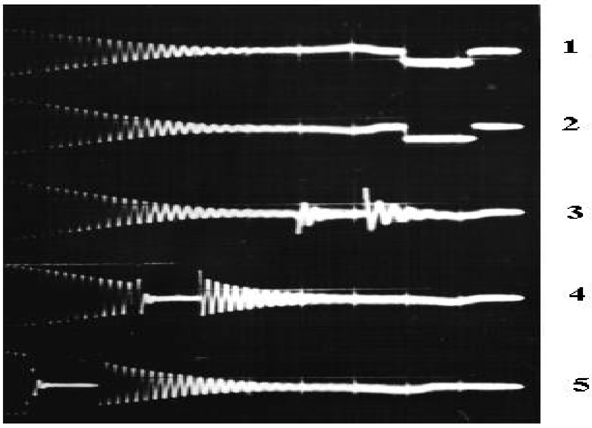

Fig. 3. Oscilloscope traces of the currents I_1 and I_2 (traces 1 and 2) and the current I_1 (3-5) on the p-electrodes when the auxiliary beam is injected with a delay relative to the termination of the current pulse of the main beam given by: 1,2) t = 1.6 ms; 3 t =1.2 ms; 4) t = 0.5 ms; 5) t = 0.2 ms. The sweep rate was 0.2 ms/div and the sensitivity was 0.01 V/div.

Spatial distributions of potential in the direction of movement of particles along magnetic field are presented in Fig.4 The distributions were taken with the Langmuir's probe, the probe being under floating potential.

The beam current being $I_B \le I_{Cr} \approx 15\, mA$, distribution of potential in longitudinal direction has typical form for velocity spread electron beams [2] – distribution of "bell" type (curve 1). Such a potential distribution leads to accelerated extractions of electrons from the drive space caused by electric fields of the spatial charge of beam. Radial localization of direct and reverse flows of electrons in the drive space coincide. The beam current being increased $I_B \geq I_{Cr}$, the form of potential in the drive space essentially changes with formation of a potential pit for electrons in the drive space center (curve 2).

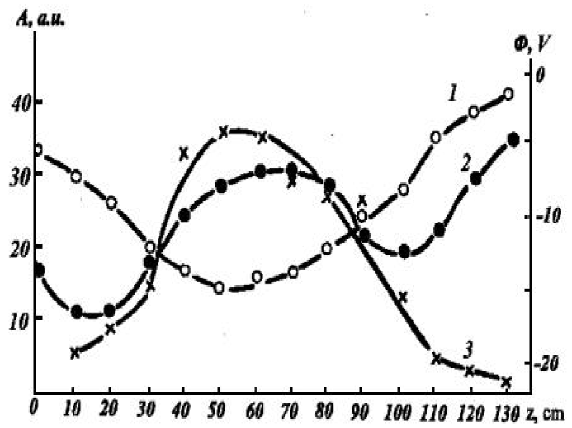

Fig.4. Spatial distribution of potential in longitudinal direction, the beam current being equal to 10 mA (curve 1), 17 mA (curve 2), and amplitude of diocotron oscillation (curve 3), B=1 kGs, U_B = 30 V, t=1 ms

Transformation of potential distribution in longitudinal direction is accompanied by excitation of the oscillations of beam density, which have been identified in [3] as the diocotron oscillations with $l = 1$ mode. In Fig. 4 the distributions of diocotron oscillations in the drive space are presented that correlate with the spatial localization of the potential pit (curve 3).

DISCUSSION

Thus we come to the conclusion that when electron beam with a large velocity spread is injected, the long life time electrons are accumulated in the drift space located in the magnetic field, the density of which being noticeable fraction of the electron density of the injected beam. The obtained results on accumulation and confinement of electrons may be explained if the dissipative force is included in the balance of forces acting on a single electron along with the electrostatic force due to the deep of the electrostatic potential and the lorentz force.

During the diocotron instability evolution the spatial charge redistribution takes place in the beam cross-section which is connected, probably, with drift of electrons in longitudinal magnetic field, radial, and azimuthal electric fields of the diocotron wave. This process accompanied not only by azimuthal redistribution of the beam density, but by radial transfer of electrons across magnetic field, that leads to increase of the radial beam dimensions and to ejection of electrons on the drift chamber walls. This phenomenon is pronounced in the central region of the drive space where the amplitude of diocotron oscillations is maximum. The variations of radial beam dimensions, and, hence, the spatial charge redistribution in longitudinal direction leads to corresponding variation of longitudinal distribution of electric potential, and appearance of self-consistent field of “potential pit” type in central region of the drive space. The distribution of stationary fields plays the role of an electromagnetic trap for of electrons localized in this part of the drift chamber. Such a self-consistent configuration of particles and fields is rather long-living, because with the beams current being $I_B \leq 20\,mA$ the lifetime of the trapped particles exceeds the electron transit time through the drive space in $4-5$ orders, and reaches10-20 ms.

.REFERENCES

1. Nezlin M.V. Dinamika puchkov v plasme, Moscow, Energoatomizdat, (1982).
2. I.Langmuir, Features of electron emission and dynamics with consideration of spatial charge and initial velocities // Phys. Rev., 21, 419, (1923).
3. V.A.Bashko, S.M.Krivoruchko, and I.K.Tarasov, Buildup of electrons with hot electron beam injection into a homogeneous magnetic field // in 16 th Europ. Conf. on Contr.Fusion and Plasma Phys.,Vol.13B, Part IV, Venice (1989), p. 1587.
4. X.P. Huang, F.Anderegg, 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. 78, 875, (1997).
5. J.J.Bollinger, D.J.Wineland, and D.H.E.Dubin, Non-neutral plasmas and crystals, laser cooling, and atomic clocks//Phys. Plasmas 1, 1403 (1994).
6. S.M.Krivoruchko, I.K.Tarasov, and V.A. Bashko, Phenomenon of current breakdown during transport of velocity-spread electron beam in vacuum channel in magnetic field // in abstracts, All-Union Seminar on Plasma Electronics, Kharkov (1988), p. 180.