SELF-CONSISTENT PENNING-MALMBERG TRAP

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. E-mail: itarasov@ipp.kharkov.ua

Self-consistent interaction of electrons with electric fields observed in drive space of velocity spread impulse electron beam in longitudinal homogeneous magnetic field during and after the injecting impulse was investigated.

The mechanism by which non-neutral electron plasma is accumulated and confined has been studied.

Physical behavior of non-neutral plasma has been studied in various non-neutral particle traps, a typical of which is Penning–Malmberg trap. It is a cylindrical trap where the radial motion of the non-neutral particles is constrained by magnetic field, while the longitudinal motions are constrained by electrostatic potential well. When used as an electron trap, the electrons from a thermal cathode are injected parallel to the magnetic field while the cathode side of the electrostatic well is open. By closing the wall dynamically, the electrons that fail to escape during the well closure are trapped. In our experiments the holding electrostatic walls arise self-consistently, simultaneously with injection of an electron beam in the space of drift. Seized there are those particles that at the moment of formation of the trap were in the space of drift.

PACS: 52.80.SM

INTRODUCTION

At the present time Penning – Malmberg trap is frequently used for investigation of non-neutral plasma properties. The description of this trap and its modifications can be found in works [1,2]. The main difference from the Penning trap is the opportunity of injection of non-neutral particles with further locking-out them inside the trap. Malmberg proposed to put ring electrodes at the edges of the trap and to use pulsed locking potential for one of the electrodes. The pulsed beam is injected through the electrode at zero (or small) potential, after filling the trap with non-neutral particles the potential on this electrode being restored. Such trap made it possible to confine particles for several minutes. For various diagnostic tasks several central ring electrodes could be used divided into several azimuthal segments.

The further improvement of the confinement of particles in such traps was accomplished using artificial capturing of particles in rotating field [3,4].

On segments of separate rings pulsed potentials were sequentially supplied, which created an effect of 'running electrical field' on one of the edges of the drift tube. This improvement was shown to allow controlling the seized plasma and to considerably increase the time of its confinement in the trap. Electron plasma could be confined in such trap for the period of one week. The value of a magnetic field thus was 4 T and the residual pressure was 3×10^{-9} Torr.

In our work, the experimental results on capture and confinement of non-neutral particles are reviewed during the passage of a pulse electron beam through the drift space. In the previous publications, during the injection and drift of electron beam with broad distribution by velocities ('hot beam') in the drift chamber, situated in homogeneous magnetic field, the accumulation and confinement of particles in central part of the drift space were observed. This could be detected by measuring the relaxation time of particles in this region after the pulse of injection had finished. The capture and the confinement of particles in homogeneous longitudinal magnetic field happen due to the formation of the non-stationary virtual cathode and, as a consequence, double sagging of the potential. Due to the dynamics of particles in the drift space a potential pit is formed into which the 'coldest' particles are captured [5]. We report results of experimental research of properties of the dynamic trap that is a modification of Penning–Malmberg trap.

EXPERIMENTAL RESULTS

The experimental setup is described in [5]. Spatial distributions of potential in the movement of particles along magnetic field are presented in Fig.1. The distributions were obtained with the Langmuir probe, the probe being under floating potential.

The beam current being $I_B = I_{CR} = 15$ mA, distribution of potential in longitudinal direction has typical shape for velocity spread electron beams [4], distribution of 'bell' type. Such a potential distribution leads to the accelerated extractions of electrons from the drive space caused by electric fields of the spatial charge of the beam. Radial localization of the direct flow of electrons coincides with that of the reverse flow in the drive space. The beam current being increased $I_B > I_{CR} = 17$mA, the form of potential in the drive space essentially changes with formation of a potential pit for electrons in the drive space center (curve 1). Transformation of the potential distribution in longitudinal direction is accompanied by excitation of the oscillations of the beam's density, which have been identified in [5] as the diocotron oscillations with $l = 1$ mode. In Fig. 1 the distributions of diocotron oscillations in the drive space are presented that correlate with the spatial localization of the potential pit (curve2). Fig.2 shows how the absolute value of the drift velocity

$$|V_{dr}| = \int V_z F(V_z, Z)dV_z / \int F(V_z, Z)dV_z \qquad (1)$$

dependence on the distance **Z** for reflected (curve 2) beam electrons. The drift velocities reach their extremum in the central region of the device at a distance of 60 – 70 cm from the entrance grid.

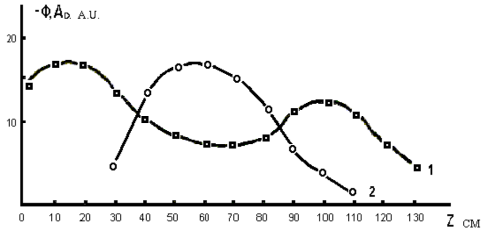

Fig. 1 Distributions potential 1, and diocotron oscillations 2 in the drive space, U_B = 30 B, I_B = 17mA, H = 1 kOe.

From Fig.2, it can also be seen that V_{dr} for the reflected electrons changes considerably between the points at **Z** = 25cm and **Z** = 90cm from the point of entrance of the beam into the drift space. The average spatial derivative of the drift velocity is 2×10^6 s^{-1} for the reflected particles. The zone of the accumulation and the confinement of electrons in the axial direction of the drift space is situated in its central part and has a highly expressed dependence on the value of magnetic field. This can be explained by the change of the radial size of the beam and, as a consequence, the distance between the beam and conducting wall.

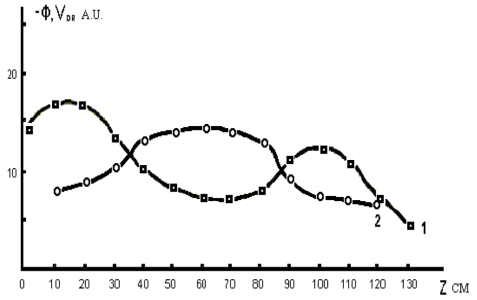

Fig.2. The potential (1) and the drift velocity of the reflected beam's particles (2) as functions of the distance Z, I_B = 17mA, H = 1 kOe.

In Fig. 3 this dependence (curve 1) is given for the diameter of the chamber of drift, 4 cm, and the diameter of the beam, 2 cm. It is obvious that with the increase of magnetic field the size of the zone of accumulation and confinement is increased in the axial direction until the value of the field reaches 1 kOe, and then decreases. The same dependence for the chamber with 15 cm in diameter, with the diameter of the beam being 2 cm (curve 2), has a maximum at the value of magnetic field, 400 Oe. In this case, the maximal size of the zone of accumulation and confinement of electrons in the drift space will correspond to the smaller value of magnetic field. It is necessary to note, that the zone of accumulation and confinement of electrons in the drift space was fixed by the presence diocotron oscillations both during the pulse of injection, and after it had finished. As a confirmation of the obtained results, a family of curves is presented describing the variation of the relative density of electrons in the drift space (in the zone of accumulation and confinement) after the termination of the pulse of injection.

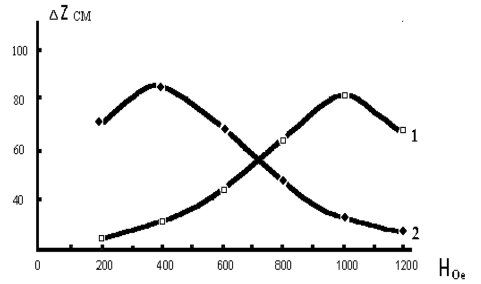

Fig.3. Dependence of the size of the zone of accumulation and confinement of electrons on the value of magnetic field, 1 – diameter of the drift tube, 4 cm, 2 – 15 cm, U_B = 30 B, I_B = 17mA.

The measurements were carried out at the parameters of magnetic fields and the sizes of the drift chamber and the beam corresponding to curve 1 at Fig. 3. The methodology of measurement of the density is described in work [6]. The dependences are presented in Fig. 4.

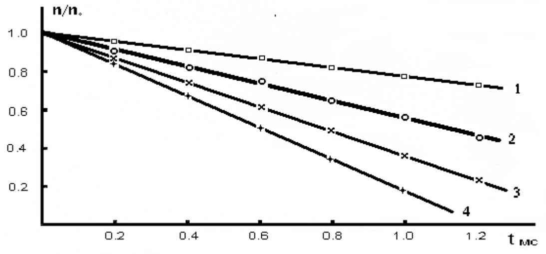

Fig.4. Relative density of the decaying as a function of time, 1 – H = 1000 Oe, 2 – H = 800 Oe, 3 – H = 600 Oe,4 – H = 400 Oe, U_B = 30 B, I_B = 17mA.

The maximal time of existence of particles after the termination of the pulse of injection is 10 ms (curve 1), which corresponded to magnetic field 1 kOe and the maximal size of the zone of accumulation and confinement of particles in the axial direction.

With the variation of magnetic field the optimization can be accomplished of the accumulation and the confinement of particles in the drift space of the electron beam. This process can be explained by the change in conditions of the interaction of particles being accumulated with a conducting wall of the drift chamber.

The optimal distance from the wall of the drift chamber does not cause the loss of particles on the wall of the chamber. The loss of the energy of the captured particles due to induced currents with the excitation of the drift-dissipative instability is possible. The given instability contains the information on the spatial localization of particles, their density, rotation speed, and the lifetime in the zone of accumulation and confinement.

CONCLUSIONS

The zone of accumulation and confinement of electrons, at injection of beams of electrons with broad velocity distribution ('hot beams') into the drift space, is situated between two maxima of the potential sagging, to which the localization of the diocotron oscillations testifies.

The change of the drift velocity of particles that move in the drift space in the opposite direction in relation to the basic flow of electrons corresponds to the distribution of the diocotron oscillations amplitude.

In this case the method of accumulation and confinement of particles differs from conditions provided in Penning – Malmberg trap. The locking electrostatic potentials on the edges of the trap are formed self - consistently in the drift space as double sagging of the potential, which is a consequence non-stationarity of the virtual cathode at the initial stage of the injection [5]. As a consequence of low value of the self-consistent potential barriers, the particles with lowest axial energy get captured in the trap. The variation of magnetic field and as a consequence of the distance between the beam and the conducting wall of the drift chamber allows to optimize the condition of accumulation and confinement of electrons in the drift space.

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. F. Anderegs, E.M. Hollmann and C.F. Driscoll. Rotating Field Confinement of Pure Electron Plasmas Using Trivelpiece-Gould Modes // Phys. Rev. Lett.-1998.-V.81, No.22.-P.4875-4878.
4. E.M. Hollmann, F. Anderegs and C.F. Driscoll. Confinement and manipulation of non-neutral plasmas using rotating wall electric field // Physics of Plasma.-2000.-V.7, No.7.-P.2776-278.
5. A.A.Bizykov, E.D.Volkov, I.K.Tarasov. Charged particles accumulation in drift space of warm electron beam during non-stationary virtual cathode existence,(this issue).
6. S.M. Krivoruchko, I.K.Tarasov. Effect of external perturbations on the expansion of nonneutral electron plasma in a magnetic field, Plasma Phys. Rep. 19(11), November 1993, p. 705 – 711, (1994 American Institute of Physics).