CHARGED PARTICLES ACCUMULATION IN DRIFT SPACE OF WARM ELECTRON BEAM DURING NON-STATIONARY VIRTUAL CATHOD EXISTENCE

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In this paper, the properties and the formation of collective electromagnetic trap for electron beam that propagates in a conducting cylinder are described. It is shown that the electron beam provides the development of an electrostatic instability in the above-mentioned conditions. The instability leads to the appearance of a non-stationary virtual cathode and the formation of electrostatic potential trap. This phenomenon takes place in the central region of the drive space where the amplitude of the electrostatic potential has two maxima. The trap confines electrons during its formation and keeps them inside the drift tube. Once seized in the trap, electrons have rather low temperature and are unstable to diocotron oscillations.

During the evolution of diocotron instability the spatial charge redistribution takes place in the cross-section of the beam, which is probably connected with the drift of electrons in longitudinal magnetic field. This process is accompanied not only by azimuthal redistribution of the beam density, but also by radial transfer of electrons across magnetic field, which leads to the increase of the radial beam dimensions and to the injection of electrons onto the walls of the drift chamber. The variations of the radial beam dimensions, and, hence, the spatial charge redistribution in longitudinal direction lead to the corresponding variation of the longitudinal distribution of electric potential, and appearance of self-consistent field of 'potential pit' type in central region of the drive space.
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INTRODUCTION

The phenomenon of loss of stability by a beam of the non-neutral particles during the propagation in vacuum, when the current of the beam exceeds certain threshold value has large practical meaning and is intensively studied [1,2]. The instability of the beam determines possible limiting current that can be passed through the drift space [3]. This phenomenon has found good experimental confirmation for the case when the velocity distribution of the particles in the beam is broad.

This work is a continuation of the experimental studies on the injection of a 'hot' electron beam into the drift space [4,5]. In the drift space a longitudinal magnetic field is generated, thus the injection of the beam is performed through the gradient of magnetic field. The length of the transient drift region is comparable with the radius of the beam. Under these conditions, the radius of the beam and the inclination of the particles' trajectories in the transient region may vary in significant range depending on the azimuthal heterogeneity of the magnetic field and the injection conditions. This leads to the energy dissipation during the injection, which may result in the induction of spatial charge in the transient region or in the drift channel near to the transient region. The spatial potential is unstable, which causes the formation of a non-stationary virtual cathode and the double sagging of the potential as a consequence [6,7]. A special attention is given to the non-stationarity of the virtual cathode that is the cause of formation of another virtual cathode displaced in space of drift, situated in the initial region of the drift space according to the direction of propagation of the electron beam.

EXPERIMENTAL SETUP

The experimental setup is shown in Fig.1.The electron beam was injected into the drift space 2 (metal tube of length L = 150 cm and diameter D = 4 cm), at whose entrance 10 and exit 11 were flat grids. The tube 2 was cut in parallel to the generatrix into two equal halves and

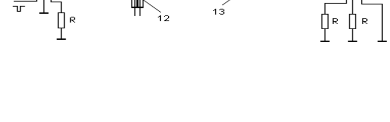

Fig.1. Schematic of the experiment: 1 - electron beam; 2 - drift tube; 3 - intermediate wave guide; 4 - carriage; 5 - electrostatic analyzer; 6 - high-frequency Langmuir probe; 7 - incandescent filament; 8 - heating cathode; 9 - anode grid; 10 - entrance grid; 11 - exit grid; 12 - double Langmuir probe; 13 - axial electrode; 14 - collector.

was made up of two sectors of angular extent 180 (π - electrodes).

Both sectors were attached to the leads and used for diagnostic purposes. The electron beam was produced by a two-electrode gun. The outside cathode 8 created both a hollow (thickness Δ = 1-2 mm) and a solid electron beam of diameter d = 2 cm. The beam energy was 20 - 80 eV.

The constant longitudinal magnetic field had a strength of H = 100 - 1500 G. The magnetic field varied over the length *L* of the drift tube by less that 5%. The range of working pressures was 10^{-4} - 10^{-7} Torr. The carriage 4 held a multigrid electrostatic analyzer 5 and high-frequency Langmuir probe 6. The density of particles in the drift space was determined from measurement of the frequency of the diocotron mode ω_d with azimuthal number l = 1.

EXPERIMENTAL RESULTS

During the experiments a number of phenomena was observed similar to the processes accompanying a well-known phenomenon of current breakdown during the propagation of a monoenergetic electron beam in vacuum, when the current exceeds certain critical value. The breakdown of the current transported through the drift space of a 'hot' beam was observed, when the current had exceeded the threshold value [3]. Fig. 2 represents the oscillograms: 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.

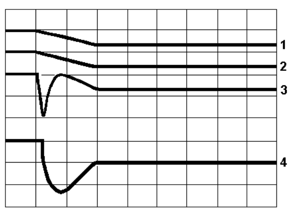

Fig. .2. Oscillograms: 1 – impulse voltage on the cathode of an electron gun, 2 - current on the in grid, 3 - current on the out grid, 4 - currents on π - electrodes. U_B = 30 V, scale - 2 μs/div, sensitivity, 1 - 5 mA/div, 2 - 1.2 mA/div, 3 - 0.25 mA/div, 4 - 4.5 μA/div.

The averaged by time (time of averaging - 20 s) distribution function of the particles by the longitudinal velocities was measured using a mobile electrostatic analyzer On Fig. 3 the distribution functions f(U) are presented for the injected beam that has passed in the drift interval: curve 1 - 10 cm, curve 2 - 40 cm, curve 3 - 70 cm. From Fig.3 it can be seen that into the drift space a 'hot' electron beam is injected that has a variation of longitudinal speed V comparable with drift speed V_{dr}. The ratio V/V_{dr}, is measured on half-height of ordinate f (U) for curve 1 is V/V_{dr}= 0.8.The beam having passed through the drift interval remains scattering, the amount of particles with low velocities increases. A transformation 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 10-20eV. The distribution function of the particles by velocity has a two-maxima shape when the emission current reaches 10mA.

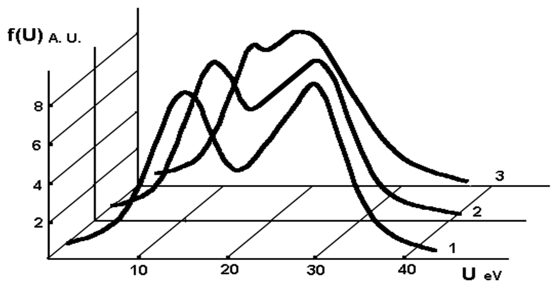

Fig. 3. The function of distribution of electron beam by velocities in three points along a magnetic field. U_B = 30 B, I_B = 17mA, H = 1 kOe. 1 - Z = 10 cm, 2 - Z = 40 cm, 3 - Z = 70 cm, I_B = 17 мА,.

The distribution of 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. In Fig. 4 the dependences of the distribution of plasma potential in the drift space along the magnetic field are presented. 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

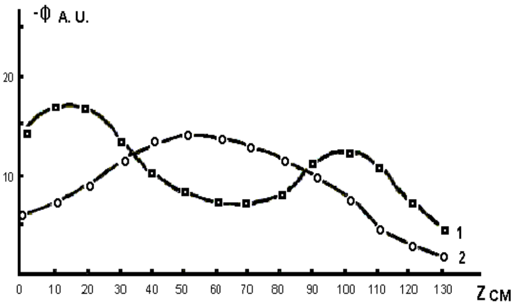

Fig. 4. Distribution of the potential in the axial direction of the drift space. U_B = 30 V, H = 1 kOe, 1 – I_B = 17 mA, 2 – I_B = 10 mA.

The behavior of the curves at Fig. 3. demonstrates that in the central region of the drift space, depending on the current of injection, there may 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 μsec for the system to make such transition.

CONCLUSIONS

The results obtained lead to the following conclusions:

1) Upon the injection of an electron beam with a broad velocity distribution into the drift space with 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.

2) Such reorganization promotes the occurrence of sagging of the spatial potential and the formation of a virtual cathode as a consequence, thus changing the dynamics of particles in drift space.

An inverse flow of the electrons takes place and a certain part of particles leaves in the 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. However, the increase of the passing current is restricted to the formation of the second sagging of the potential that is situated further in the axial direction of the drift space and is formed due to the second maximum (that possesses higher energy) of the function of distribution.

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 present in the drift space upon the occurrence of double sagging.

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