HIGH FREQUENCY OSCILLATIONS IN THE HOLLOW CATHODE AND THEIR INFLUENCE ON ITS OPERATION

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Abstract

A mechanism of megaherz oscillations in the hollow cathode is developed based on the process of interaction of electron current and plasma ions in the working cavity.

The conclusions that transpire from the analysis of the mechanism of oscillations, such as availability of oscillations threshold, their frequency, the behaviour of emission intensivity variation are in good agreement with experimental data.

Introduction

To develop effective hollow cathodes (HC) that are used in plasma accelerators with closed drift of electrons as cathodes-neutralizers it is necessary to understand in detail the physical processes occuring in it and the extent to which they affect the HC operation. One of such processes is high-frequency oscillations (~ 1 MHz) of HC parameters, such as current, emission intensity, ets. Their excitation requires energy expenses and, consequently decreases the HC operation efficiency.

Experimental results

The experiments were carried out on W-Ba-based HCs using Xe gas as propellant in regimes characteristic of cathodes-neutralizers in accelerators with closed drift of electrons.

Two operation regimes of HC were found. Their qualitative difference was oscillations of current in its circuit and the glow which was observed visually in the region of HC diaphragm in one of regimes.

In the other regime there were no glow and current oscillations. Change-over from one regime to the other was effected by adjustment of Xe flow rate. The regime with out oscillations corresponded to the higher flow rate.

Mechanism of oscillations

The report suggests a mechanism of these oscillations allowing explanation of the experimental results.

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Let us consider dynamics of electron current flow through the HC cavity in the one-dimensinal case. The system of equations describing the motion and the interaction of electron and ion components of plasma has the form:

$$\begin{cases} \frac{\partial V_e}{\partial t} + V_e \nabla V_e = -\frac{e}{m}E - \nu V_e - \frac{T_e}{m}\frac{\nabla n_e}{n_e}\ ;\ n_e = n_i\ ; \\ \frac{\partial V_i}{\partial t} = \frac{e}{M}E\ ;\ \frac{\partial n_e}{\partial t} + \nabla(n_e V_e) = 0\ ;\ \frac{\partial n_i}{\partial t} + \nabla(n_i V_i) = 0\ , \end{cases} \tag{1}$$

where V_e, V_i, n_e , n_i, m, M are velocities, densities, masses of electron and ion, respectively;

T_e is electron temperature ("cold" ions);

e is charge;

ν is frequency of collisions;

E is field stregth.

Assuming the plasma in the cavity to be homogeneous, from (1) we shall obtain the stationary value of electron velocity

$$V_e^0 = -\frac{e}{m}E_0\ ; \tag{2}$$

for ions we consider $V_i = 0$, as $V_i << V_e$.

On wards, expanding system (1) in a series about the small parameter A in the form of $A \sim \exp\{-i\,(wt - kx)\}$ (x axis with respect to current), and neglecting the electron inertia in the region of frequencies under consideration, from the equations of motion and continuity, for electrons we shall obtain

$$(\omega - k\,V_e^0 + i\,\frac{k^2 T_e}{m\nu})\,n_e^1 - \frac{\overline{k}\overline{E}^1}{m\nu}\,n_e = 0 \tag{3}$$

whereas for ions we obtain

$$n_i^1 = i\,\frac{e n_i}{M\omega^2}\,\overline{k}\overline{E}^1\ . \tag{4}$$

Putting the disturbance of densities from (3) and (4) equal, we shall write the final dispersion equation

$$\omega^2 + i\,\alpha\,\nu\,(\omega - kV_e^0) - \frac{\kappa^2 T_e}{M} = 0\ , \tag{5}$$

where $\alpha = m/M$.

Analysis and conclusions

The analysis allows explanation of the following experimental facts.

1. Existance of two regimes or the oscillations threshold with respect to gas flow rate directly follows from dispersion equation (5) from the condition $\mathrm{Im}\,\omega > 0$, or [1]

$$V_e^0 > (\frac{T_e}{M})^{1/2}\ . \tag{6}$$

With the account of (2) and the known gasdynamic relation $\nu = (\frac{T_e}{m_e})^{1/2}\,n\,\sigma$, where σ is cross-section of scattering, condition (6) is transformed into following

$$n < \frac{eE}{\alpha T_e^{1/2} \sigma}; \qquad (7)$$

or $n < 10^{16}$ cm^{-3} for typical HCs.

2. Frequency of oscillations is determined by the relatiion

$$\omega = k \left(\frac{T_e}{M}\right)^{1/2}.$$

For a HC ω = 1 MHz ($k = 2\pi/l$, where l is the size of cavity, l = 3 mm).

3. The disturbances that are built up in the plasma are of "ion sound" character. The fulfillment of condition (6) makes the current flow regime "supersonic", i. e. it changes it from laminar into turbulent that leads to additional losses of energy which is consumed mainly for the heating of electrons [2]. The increase of T_e automatically intensify processes of excitation of Xe atoms and hence, the plasma glow.

References

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