INFLUENCE OF ION MOBILITY ON PIERCE INSTABILITY DEVELOPMENT DURING COMPENSATED ION BEAM TRANSPORT

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1 INTRODUCTION

Problem of Pierce instability development (see [1-4]) is important in problem of transporting of high-energy ion beams neutralised by electrons. Also it is actual in gas-discharge sources of ions. In the latter case the ions are low-energy. The Pierce instability is also important in plasma lens for ion beam focusing (see [5-7]). In the first case the electrons are injected together with ions for neutralising their space charge. In the second case electrons are generated in discharge together with ions. In the third case the electron cloud is created externally or selfconsistently by ion beam and provides of ion beam focusing. In paper [8] it has been shown that ions with zero initial and with nonzero initial velocities effect in different ways on threshold of Pierce instability development. While high-energy ions widen the stable region in parameter space. But low-energy ions lead to without threshold instability development. In this paper the physical reason of different ion effects is considered.

We consider the most unstable perturbation at above threshold value π of Pierce parameter $\alpha\equiv L\omega_p/V_{oe}$. Here ω_p is the plasma frequency of electrons, V_{oe} is the injection electron velocity, L is the system length. Namely, we consider the hump of electric potential $\varphi(z,t)$. The electric potential is maximum one inside a system and equals zero on its boundaries $\varphi(0)=\varphi(L)=0$. We take into account the finite value of ion mass. There are two cases for injection ion velocity V_{oi} . We investigate the case of a high-energy ions $V_{oi}\neq 0$ as well as low-energy ions $V_{oi}=0$. In the second case we take into account the finite thermal velocity of ions. In the first case the ions are injected in a system on the same boundary as electrons. In the second case a half of ions with positive velocities $V > 0$ are injected from the same boundary, as the electrons, and half of ions with negative velocities $V < 0$ are injected with the opposite boundary.

2 STATIONARY FIELD DISTRIBUTION IN THE PIERCE DIODE WITH TAKING INTO ACCOUNT THE ION MOBILITY

We consider the quasistationary distribution of electric potential $\varphi(z,t)$ in the system with taking into account the ion mobility. From equations of continuity and motion of particles expressions for densities of electrons n_e , high-energy n_{ih} and low-energy ions n_{iL} follow:

$$n_e=n_o/(1+2e\varphi/m_eV_{oe}^2)^{1/2},\ n_{ih}=n_o/(1-2e\varphi/m_iV_{oi}^2)^{1/2},\ n_{iL}=n_o\exp(-e\varphi/T_i) \quad (1)$$

T_i is the temperature of low-energy ions, V_{oi} is the injection velocity of high-energy ions; n_o is the particle density on the boundary of injection. From (1) one can see that the electron dynamics in the field of perturbation leads to formation of noncompensated volume positive charge in the system

$$\delta n= n_o[1-1/(1+2e\varphi/m_eV_{oe}^2)^{1/2}] \approx \approx n_o(e\varphi/m_eV_{oe}^2)[1-1.5(e\varphi/m_eV_{oe}^2)] \quad (2)$$

From (1) it also follows that

$$\delta n_{ih}\approx n_o(e\varphi/m_iV_{oi}^2)[1+1.5(e\varphi/m_iV_{oi}^2)] \quad (3)$$

dynamics of high-energy ions leads to increase of this noncompensated positive charge, because the ions slow inside a system. The nonlinearity reduces noncompensated positive charge at $\beta\equiv m_eV_{oe}^2/m_iV_{oi}^2<1$ and increases it at $\beta>1$. Also one can show that the nonlinearity, determined by trapped electrons (in the field of perturbation), reduces noncompensated positive charge. Frm (1) one can see also that the contribution in noncompensated charge by low-energy ions is opposite to the contribution of high-energy ions. Namely, the low-energy ions lead to reduction of noncompensated charge

$$\delta n_{iL}\approx -n_o(e\varphi/T_i)[1-(e\varphi/2T_i)] \quad (4)$$

From equations of continuity and motion of electrons, high-energy and low-energy ions one can obtain that the nonstationary terms in these equations reduce the noncompensated positive charge

$$\partial_z \Delta n_e \approx 2n_oe\partial_t\varphi/m_eV_{oe}^3\ ,\ \partial_z\Delta n_{ih} \approx -2n_oe\partial_t\varphi/m_iV_{oi}^3\ ,\ \partial^2_z\Delta n_{iL} \approx -n_om_ie\partial^2_t\varphi/T^2_i$$

Here Δn_e , Δn_{ih} , Δn_{iL} are contributions of nonstationary terms into the perturbations of densities of electrons, high-energy and low-energy ions, $\partial_t\varphi=\gamma\varphi$, γ is the growth rate of the perturbation amplitude.

Substituting (1) in the Poisson's equation and using normalisation n_e and n_i on n_o , t on ω_{pe} , z on V_{oe}/ω_{pe}

, φ on $m_eV_{oe}^2/e$, $\phi=e\varphi/m_eV_{oe}^2$, $x=z\omega_{pe}/V_{oe}$, one can derive the equation for spatial distribution of potential

$$(\partial\phi/\partial x)^2 = (1+2\phi)^{1/2} - (1+2\phi_o)^{1/2} - [(1-2\phi\beta)^{1/2} - (1-2\phi_o\beta)^{1/2}]/\beta \qquad (5)$$

$\beta = m_eV_{oe}^2/m_iV_{oi}^2$ is universal parameter, determining the system behaviour [8], and is the relation of kinetic energies of electrons and ions.

Similarly (5) one can derive the equation for spatial distribution of potential for the case of low-energy ions

$$(\partial\phi/\partial x)^2 = (1+2\phi)^{1/2} - (1+2\phi_o)^{1/2} + [\exp(-\phi\eta)-\exp(-\phi_o\eta)]/\eta \qquad (6)$$

$\eta= m_eV_{oe}^2/T_i$. In the case of small amplitudes the contribution of mobility of high-energy ions is reduced to multiplication of a right member in (5) on a factor $(1+\beta)$. Influence mobility of low-energy ions is reduced to that the equation (6) does not have quasistationary solutions, because $\eta>>1$. Thus, as earlier was shown, the Pierce instability is developed without threshold in the case of low-energy ions.

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