FEATURES OF AN ION BUNCH COLLECTIVE ACCELERATION BY A BOUNDARY OF A DISTRIBUTED VIRTUAL CATHODE

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Numeral simulation of an ion bunch (IB) charge influence on a boundary motion of a distributed virtual cathode (VC) has been performed. It has been found that the IB changes the speed of VC boundary movement the more the nearer the IB is to the VC boundary. As a result, the IB can control in certain limits the VC border motion.

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A method of collective ion acceleration by a potential overfall, which exists at an interface between two different states of an electron stream, namely, the state with and without VC, was presented in [1]. It is shown experimentally [2] and by means of numeral simulation [3] that the potential overfall predicted in [1] does exist and it is possible to speed-up its motion.

The aim of this paper is to study a longitudinal stability of ions accelerated by a potential overfall and to estimate an influence of accelerated IB charge on a process of acceleration.

An accelerating structure, in which a method of acceleration offered in [1] can be realized, is schematically presented in Fig.1. It comprises flat parallel electrodes providing a counter propagation of electron beams (EB). Electrons are accelerated in 'cathode 1 – greed 2' gaps by a potential difference *Uk* and enter a drift space between grounded grids.

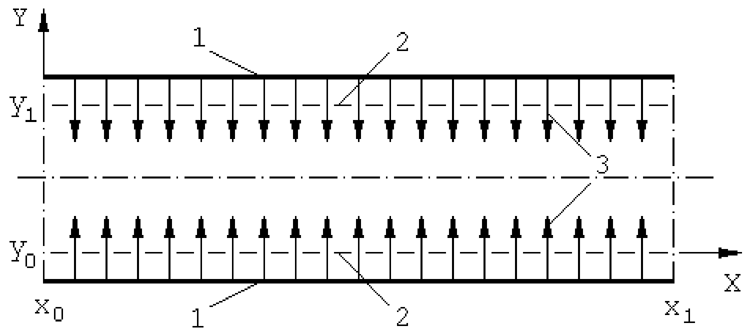

Fig.1. Scheme of accelerating structure:
1 – cathode; 2 – greed-anode; 3 – counter propagating electron beams

In accordance with [4], the state of stream in space of drift is determined by the dimensionless value $J=2\times J_{inj} / J_d$, where J_{inj} – is the density of EB injected by one gap, and J_d is the density of EB, determined by the *3/2* law for the diode in which the applied potential difference is Uk, and the cathode – anode gap is $Y_1 - Y_0$.

As *J* increases from a zero to $J < 4$, all the electrons cross the drift space. At $J=4$ there is irreversible transition of stream into the state, when part from the injected into the drift space electrons comes back to the grids, as if they were emitted by the cathode located in the drift space. This EB state one calls the state with VC. After the origin the state with VC exists at $2.9 < J$. At $J = 2.9$ state with VC irreversibly passes to the state without VC.

It follows from above said, that there is a hysteresis of states. For every value *of J* in the interval of hysteresis ($2.9<J<4$) EB may exist in the VC state or in the state without VC.

If in the device shown in the Fig.1 J is in the interval of hysteresis, a situation is possible when at $x_0<x<x_b$ there is the state without VC, and at $x_b < x < x_1$ there is the state with VC [2, 3]. The coexistence of these states shows up, generally speaking, in movement the boundary between them. There is only one value of $J=3.4$, which the boundary is immobile at. At $J >3.4$ state with VC takes in the state without VC, at $J <3.4$ the state without VC takes in the state with VC. Speed of the boundary moving the more, the nearer *J* to the border of hysteresis. If *J* does not depend on x, speed of the boundary movement is constant, if $J = J(x)$, speed of the boundary movement also will depend on *x*.

Since electron charge density in the state without VC is less than in one with VC, the potential dependence on the x coordinate at the device axes is given by next shape. Far from a border practically permanent value of potential, in area of border monotonous transition is to other more low permanent value. By this overfall of potential it is possible to accelerate ions. For this purpose it is needed, that the state without VC absorbs the state with VC with speed increasing along the device. It can be obtained by the suitable monotonous diminishing of *J* in the direction of ions acceleration.

It should be expected that IB charge can influence on the speed of boundary moving. The numeral simulation of such influencing is conducted by the method of macroparticles in a cell subject to the condition following: the device (fig.1) is unbounded along the z axis, *x* component of the electric field at x_0 and x_1 is equal to the zero; electrons move only along the axis y; IB is unlimited along the axis z uniformly charged hard bar with

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the elliptic transversal section. The ratio of longitudinal axis of ellipse toward transversal one is equal 2, the size of longitudinal axis is comparable with the size of overfall of potential along the axis x. Maximal value of IB charge density has been chosen from the condition of possibility of its withholding by the fields of EB and was $-1.7\times Q$, where Q is the EB charge density at the moment of injection. The influence of the EB field on IB motion was not taken into account at the modeling.

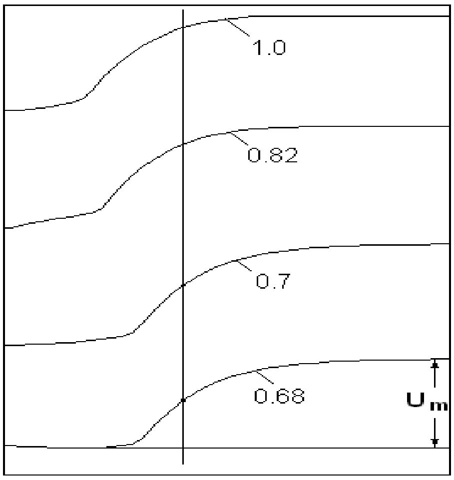

Fig.2. Location of overfall of potential vs IB. Near the curve the charge value in relative units. Position of the IB center marked by a vertical line

First modeled situation is a mobile overfall and immobile IB for a case, when in the initial moment of time IB is located in the state without VC. $J = 3.7$, i.e. more than *3.4*, and the state with VC absorbs the state without VC, the overfall move up to IB. The final states are shown in Fig.2 for cases, when IB stops motion of the overfall. It is visible from Fig.2, the more IB charge, the larger IB distance from the center of the overfall. Hence, it may conclude, the retarding IB effect on the overfall is the more the nearer it to the center of the overfall. The lowest charge value *0.68* is near to the critical value. At the smaller charge values IB stops to restrain the overfall motion. The potential value at the place of IB location for a curve *0.68* equals to about *1/2Um*.

In the next modeled situation $J<3.4$, the state without VC absorbs the state with VC. IB moves with permanent velocity from a region without VC and catches up the overfall. As calculations show, two variants are realized: 1) at approaching IB to the overfall the overfall velocity increased and achieved the IB one. In future there is their synchronous motion; 2) at the IB velocity higher than some critical value, IB cross the overfall and the synchronous motion is not realized.

Fig.3 shows dependences of the overfall velocity from J at the absence of IB (curve 1) and at the presence of IB (curve 2). Points of curve 2 a little lower than the critical IB velocity value. It should be noted that in the moving system of IB – overfall the loss of control takes place at the same location IB in relation to the overfall, as in the case of the immobile system (lower curve in Fig.2). Thus, stable motion of the system takes place, when IB located at the x-coordinate, for which the value of potential is $U(x) > 1/2\ Um$ (Fig.2).

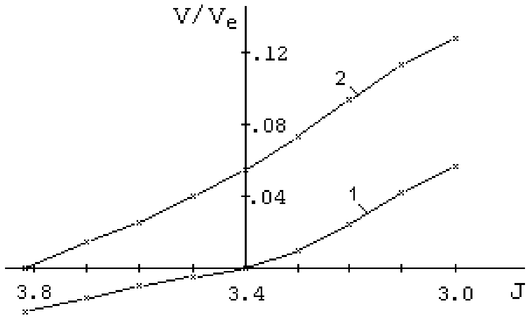

Fig.3. Dependence of dimensionless overfall velocity on the density of EB injection current. 1– overfall without IB; 2 – is overfall with IB. IB charge = $-1.7\times Q$; V_e - speed of electrons at injection into the drift space

As seen from Fig.3, IB charge can substantially change velocity of overfall. If the stable IB acceleration is possible under these conditions, IB energy at the output may be about four times higher than at IB with a small charge.

In approaching of small IB charges, the problem of its longitudinal stability is solved very simply.

Let a charged particle move in the electric field, the potential of which in the laboratory system of coordinates is described in by the function $U\left(x - at^2/2\right)$. Then in the frame of reference, moving with acceleration a in relation to the laboratory system of coordinates, distribution of the potential looks like (see the Appendix):

$$U_{ac}(x) = U(x) + (m/e)a \cdot x . \qquad (1)$$

In Fig.4, the dependences built on formula (1) for the sigmoidal function $U(x)=1/(1+e^x)$ at the different values of coefficient a. are presented.

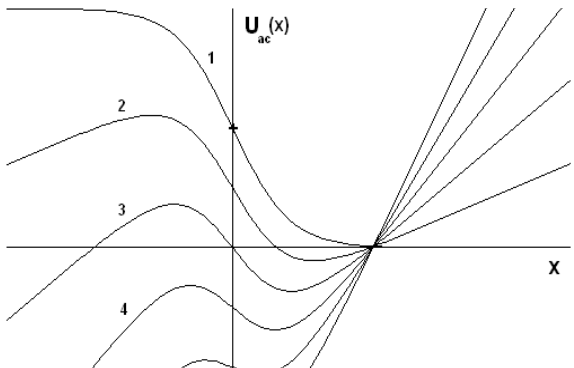

Fig.4. Potential distribution in the systems of coordinates, which moving with different accelerations a in relation to the laboratory system of coordinates. For curve 1 a = 0; the curve number is increased with the increase in a

As seen from Fig.4, there is an interval of values of a at which steady acceleration of the charged particle is possible. It is also evident that in the case of stability minimum of potential pit and center of IB are located at the coordinate x, for which $U(x) < 1/2$.

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As indicated above, the stability of the system overfall – IB takes place if $U > 1/2$ in the IB center location. Thus, the increase in the IB charge in the accelerating device with the monotonous diminishing of injected electrons current density in the direction of IB acceleration is limited by the growth of instability of the system overfall – IB.

Possibly, this restrictions may be lifted, if to conduct acceleration with the by turn changing of foregoing stabilities, by analogy with the alternating-phase focusing.

APPENDIX

Let a charged particle move in an electric field, potential of which in the laboratory system of coordinates is described by a function $U(x,t) = U(x - at^2/2)$.

Then the equation of particle motion looks like

$$m\ddot{x} = -e\frac{\partial U(x - at^2/2)}{\partial x}. \qquad (A1)$$

After replacement of variable on a formula $\xi = x - at^2/2$ Eq. (A1) acquires a kind

$$m(\ddot{\xi} + a) = -e\frac{dU(\xi)}{d\xi}. \qquad (A2)$$

Multiplying both parts of Eq.(A2) by $\dot{\xi}$ and integrating, we will get the expression for the potential in the frame of reference, moving with acceleration **a** in relation to the laboratory system of coordinates

$$U_{ac}(\xi) = U(\xi) + \frac{m}{a}a\xi .$$

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ОСОБЕННОСТИ КОЛЛЕКТИВНОГО УСКОРЕНИЯ ИОННОГО СГУСТКА ГРАНИЦЕЙ РАСПРЕДЕЛЕННОГО ВИРТУАЛЬНОГО КАТОДА

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Проведено численное моделирование влияния заряда ионного сгустка на скорость перемещения границы распределенного виртуального катода. Обнаружено, что заряд ионного сгустка изменяет скорость перемещения границы виртуального катода тем больше, чем ближе ионный сгусток к границе виртуального катода. Этот эффект приводит к тому, что в определенных пределах ионный сгусток может управлять перемещением границы виртуального катода.

ОСОБЛИВОСТІ КОЛЕКТИВНОГО ПРИСКОРЕННЯ ІОННОГО ЗГУСТКУ МЕЖЕЮ РОЗПОДІЛЕНОГО ВІРТУАЛЬНОГО КАТОДА

А.Г. Лимар

Проведено чисельне моделювання впливу заряду іонного згустку на швидкість переміщення межі розподіленого віртуального катода. Виявлено, що заряд іонного згустку змінює швидкість переміщення межі віртуального катода тим більше, чим ближче іонний згусток до межі віртуального катода. Цей ефект призводить до того, що в певних умовах іонний згусток може керувати переміщенням межі віртуального катода.