POSSIBILITY OF THE USAGE OF ACTIVE MEDIA WITH ELECTRON BEAMS FOR ION ACCELERATION

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Brief analysis of publications, which have aroused considerable interest in physics of virtual cathode (VC) in connection with the problem of ions acceleration by electron beams (EB), results of distributed VC numeral simulation and variants of the systems in which the distributed VC can be used for acceleration of ions are presented.

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INTRODUCTION

The basic publications, which have defined direction of our researches, are placed in [1-4]. Attractively simple method of ion bunch (IB) acceleration has been offered in [1]. IB, placed in rectilinear EB, excites electrostatic wave and is accelerated by its field, providing the synchronous moving with the accelerating wave. The transversal stability of IB is provided by a volume charge of EB, placed in the longitudinal magnetic field. Unfortunately, it appeared that the excited wave cannot overcome repulsive action of the IB volume charge in longitudinal direction, and this method remained unrealized.

The results of ion acceleration in linear EB, generated in plasma filled diodes [2], and EB injected into a neutral gas are described [3,4]. Ions acceleration takes place, if the current of EB exceeds the value at which VC appears. Maximal energy of accelerated protons can exceed energy of EB approximately in 10…20 times. This ratio practically does not rely from the EB energy in the range from 100 eV to 2 MeV. Maximal energies of heavy ions do not rely on multiple of their charge. The ions of different masses have the same maximum speed.

In spite of numerous attempts to account for the process of ions acceleration in EB, it is not formulated now.

Set forth above results allow doing the following conclusions: 1. For providing of longitudinal stability of accelerated IB it is needed: either to place IB in EB, possessing amplifier properties (it will allow to decrease the IB charge), or place IB in EB, where an accelerating wave is already created, leaving for IB, if it is possible, only function of synchronization of acceleration wave motion (in definite limits); 2. The mechanism of ions acceleration in EB is based on the VC properties; 2.1. This mechanism of acceleration practically does not depend on energy of EB; 2.2. Ions are accelerated by a group.

THE VC FEATURES WHICH IT IS POSSOBLE TO USE FOR ION ACCELERATION

The first to be described was VC for EB of the flat geometry [5] is shown in Fig.1. Here all electrodes are endless planes parallel to each other. Electrons are accelerated in a gap cathode 1 - net 2 and are injected into a drift space between net and collector 3. The U_k potentials is attached between cathode and net. According to the theory [5] the state of electron stream in the drift space is determined by the dimensionless magnitude $J = J_{inj}/J_d$, where J_{inj} – density of injected current and

$$J_d = \frac{4}{9}\varepsilon_0\sqrt{\frac{2e}{m}}\frac{U_k^{3/2}}{(y1 - y0)^2}.$$

In Fig.2 the dependence of potential in the middle plane of the drift space from J is presented. As J increases from zero to $J < 8$, all the electrons, injecting in the drift space, cross it and are taken up by the collector. At $J = 8$ there is irreversible transition of beam to the state with VC, where part of electrons in the drift space comes back toward the net. After the origin the state with VC exists at $J > 4$. AT $J = 4$ the state with VC irreversibly passes to the state without VC. At the numeral simulation of the state with VC was discovered [6], that the theoretical results, presented in [5], must be specified: there is an oscillations in the state with VC, and owing to their presence VC disappears at $4 < J_{min} \cong 5{,}8$.

It should be noted the following features of the dependence, shown in Fig. 2: 1) two states, different by the size of potential, correspond to every value of J in the hysteresis loop; 2) the least perturbation causes considerable changes of the states of EP on the borders of the hysteresis loop. It is given below, as these features can be used for IB acceleration.

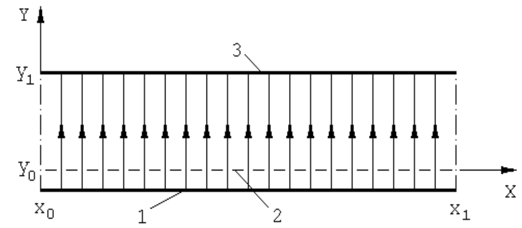


Fig.1. The chart of the explored device: 1 – cathode; 2 – net; 3 – collector. Net and collector are shorted out

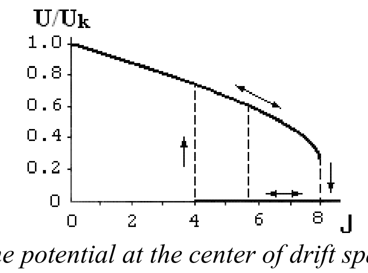
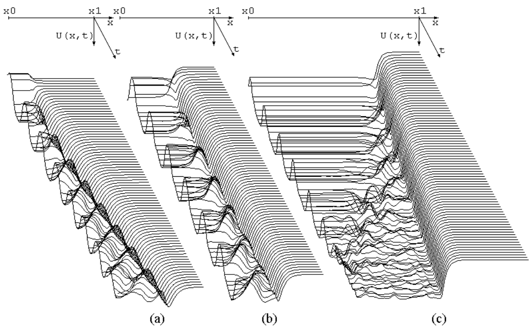


Fig.2. The potential at the center of drift space versus density of injected current

The behaviour in time of a next state of the system (Fig.1) is of interest. Lets the state corresponding to some value of J in the interval of hysteresis and the value of potential on the high bound of hysteresis loop is present in one semi plane, and the state corresponding to the same value of J, but the value of potential on the low bound of hysteresis loop in the other semi plane. The same distributed structures behaviour is described in literature (see for ex. [7]). In our case, generally speaking, a border between states moves, there is absorption of one state by the other. There is only one "equilibrium value" of J at the hysteresis interval such that a border between the states is at rest. The greater J value differs from "equilibrium value", the greater velocity of a border movement. In our case, if J value more than "equilibrium value", the state with VC absorb the state without VC. If J value less than "equilibrium value", the state without VC absorb the state with VC.

The set forth model has verified by the results of the experiment [8] and numeral simulation [9]. The behaviors of the border between the states are shown in Fig.3. In the case (a) the state with VC absorb the state without VC, in the case (b) the border between the states is immobile, in the case (c) the state with VC absorbed by the state without VC. There is the overfall of potential and accordingly electric field at the border between the states. This field may be used for IB accelerations.



a b c

Fig.3. The potential in the middle plane of the drift space as a function of the x and t for the different injecting EB density J: a) 7.88; b) 7.4; c) 5.85

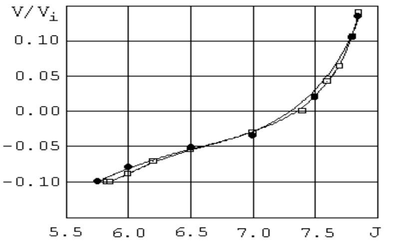


Fig.4. Velocity the border between the states versus the injecting EB density J

It is shown in Fig.4 that the velocity of the border movement depends on J. It is allows providing IB acceleration and synchronization of its moving with the accelerating wave by the suitable selection of J dependence from x coordinate.

The numeral simulation shows that there are two modes of oscillation for EB of considered geometry: oscillation with relatively large amplitude with the frequency **ν** and relatively small amplitude with the frequency **3ν** [6,9]. In Fig.5 the border between the states behavior is shown, when the state with the small amplitude oscillation absorb the state without VC (analogue of the variant (a) Fig.3). As is seen from Fig.5, the border between the states constitutes the potential pit allowing accelerating IB at absorption of the state without VC by the state with VC.

If to assume that protons can be accelerated to the highest border velocity (see Fig.4), the protons energy will be more than 20 times greater than the energy of electrons at injection.

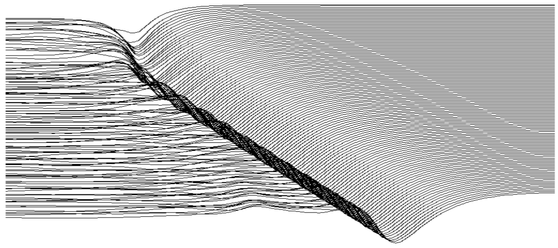


Fig.5. The state with VC with small amplitude of oscillation absorbs the state without VC

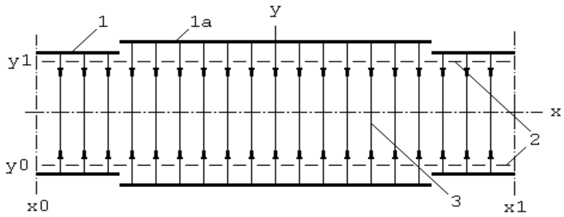
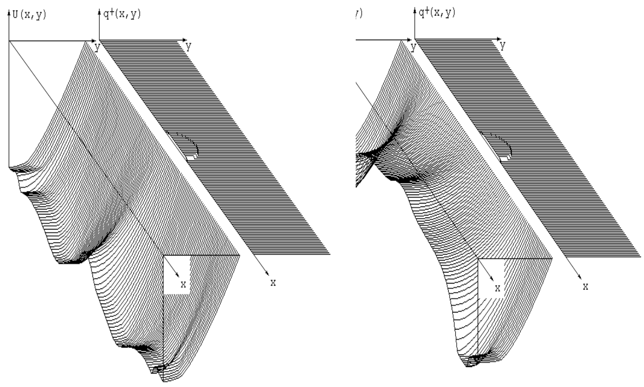


Fig.6. Scheme of the accelerating period: 1,1a – cathodes; 2 – nets; 3 – meeting electronic bunches

The foregoing properties of the hysteresis loop borders allows to offer the method of IB acceleration wherein the synchronism of an accelerating wave and IB moving provides by IB [10].

The possible variant of accelerating period (AP) for realization of the offered method is schematically represented in Fig.6. AP is symmetric in relation to the axes of x and y and contains cathodes 1, 1a and the nets 2. The upper and lower nets have the same potential. Potentials of cathodes 1 and 1a are different. It allows at the limited emission capability of cathodes to form the state with VC with periodically changing parameters along the x axis. In particular, it is possible to create in the central part of AP the VC state close to the left border of the hysteresis loop. In this case it is possible to produce substantial alteration of the state of stream and accordingly electric fields in the central part UP by small perturbation. IB can be such perturbation, entering in UP along the x axis. The given below results are obtained in supposition, that IB is the evenly charged bar endless along the z axis. Section of the bar in the xy plane is ellipse with semiaxes along the axes of x and y accordingly 64 and 16 units. The IB charge have been selected so that the change of the potential value, caused by the IB presence did not exceed 25%.



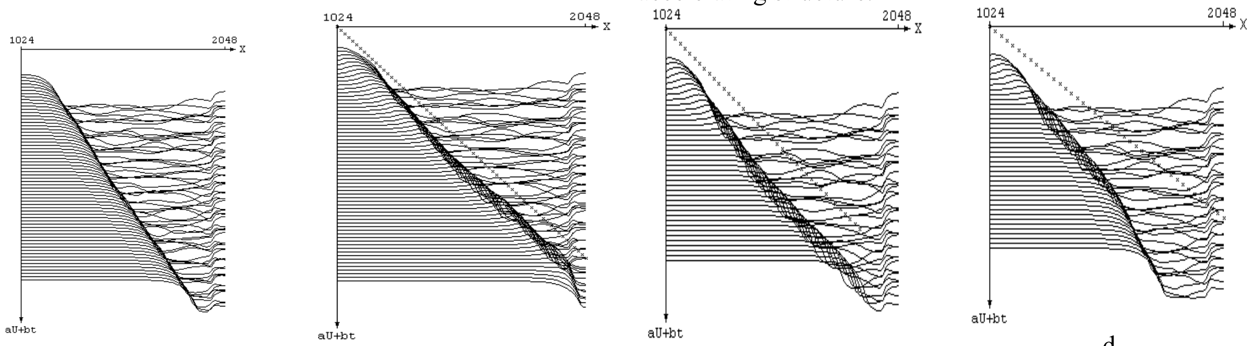
a b

Fig.7. Distributing of potential and the IB charge a) in the case of presence VC along all AP and b) in the case of absence VC in the central part of AP

The initial distributing of potential in AP is shown in Fig.7a. IB passes the initial half of AP without acceleration. In Fig.7b distribution of potential after transition of central part of EB in the state without VC. From Fig.7b it is visible that the IB acceleration takes place on the exit part of AP. The resulted cycle of acceleration will repeat oneself in subsequent AP until the IB speed will not get around the speed of the VC border movement.

Of particular interest is the influence of IB on the speed of the VC border movement. IB speed influence on the speed of the VC border movement qualitatively presented in Fig.8a–d. In Fig.8a motion of the border between the states in the absence of IB is given. In Fig.8b,c IB moves with a speed which exceeds the border speed presented in Fig.8a. In Fig.8d the case is given, when IB already does not handle of the border moving.

It is entirely possible that the presence of the synchronizing influence of IB on the VC border moving allows to reduce tolerances on the parameters of accelerating structure.



a b c d

Fig.8. Potential in the plane $y=(y_0+y_1)/2$ vs x and t; (x) IB position vs t

CONCLUSIONS

1. The described original methods of acceleration meet the conditions, formulated in p.1 of Introduction.

2. The expected ratio of the energy of accelerated ions to the energy of EB in the offered method exceeds the values which have obtained in the higher quoted experiments [2-4].

3 The maximum energy of ions must not rely on multiple of their charge, and the ions of different masses must have the same maximum velocity in the foregoing variant of ion acceleration in mobile potential pit. The same situation was observed in the experiments [2-4].

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О ВОЗМОЖНОСТИ ИСПОЛЬЗОВАНИЯ АКТИВНЫХ СРЕД С ЭЛЕКТРОННЫМИ ПОТОКАМИ ДЛЯ УСКОРЕНИЯ ИОНОВ

А.Г. Лымарь

Приведены краткий анализ публикаций, которые определили интерес к физике виртуального катода (ВК) в связи с проблемой ускорения ионов электронными потоками (ЭП), результаты численного моделирования поведения распределенного ВК и варианты систем, в которых распределенный ВК может быть использован для ускорения ионов.

ПРО МОЖЛИВІСТЬ ВИКОРИСТАННЯ АКТИВНИХ СЕРЕДОВИЩ З ЕЛЕКТРОННИМИ ПОТОКАМИ ДЛЯ ПРИСКОРЕННЯ ІОНІВ

А.Г. Лимар

Приведені короткий аналіз публікацій, які визначили інтерес до фізики віртуального катода (ВК) у зв'язку з проблемою прискорення іонів електронними потоками (ЕП), результати чисельного моделювання поведінки розподіленого ВК і варіанти систем, в яких розподілений ВК може бути використаний для прискорення іонів.