LOW-FREQUENCY REB MODULATION AND ACCELERATION OF IONS IN A SUPERCRITICAL MODE DURING PLASMA INJECTION

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Low-frequency modulation of a high-current relativistic electron beam (REB) and acceleration of ions in the first section of a collective ion accelerator was studied experimentally. Low frequency modulation of supercritical high-REB was obtained due to periodic compensation of a virtual cathode charge by plasma ions. An ion flow was produced by an electric field of virtual cathode when plasma assists. Plasma was formed by the four Bostick plasma guns placed at equal distances along the periphery of the drift chamber. The low-frequency modulation with depth 10 % at frequency 46 MHz was obtained. The ion energy was measured using the magnetic analyzer. The ion energy that probably was obtained in the potential well of the virtual cathode exceeded the REB energy.

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1. INTRODUCTION

The idea of time-space modulation of REB is the basis of a two-section ion accelerator. In such an accelerator, a slow wave synchronous with accelerated ions is formed in the electron beam. In the plasma vircator the external plasma injection, in particular, in the course of plasma anode creation, causes disappearance of a virtual cathode because of compensation of its space charge by ions. Its subsequent relaxation formation occurs in the case of plasma disappearance. Thus, there is a capability of low frequency REB modulation, which is determined by the time of ions flyover.

The purpose of this paper is the implementation of low-frequency time modulation and realization of pre-acceleration of ions in the first section of a collective ion accelerator with using an external plasma source.

2. NEAR-WALL PLASMA ANODE

In the first section of the collective ion accelerator, where ions are pre-accelerated by an electrostatic field of a space charge of the virtual cathode, a source of ions is the plasma anode formed by an external plasma source. In Fig. 1 the scheme of the first section of collective ion accelerator is shown. The plasma anode is formed by a synchronous operation of four plasma guns (4) of Bostick type with voltage breakdown on a surface of organic glass. The guns are placed in the same plane on peripherals of the cylindrical drift chamber (6) of the accelerator. For plasma configuration the change of initial radial motion of neutral plasma from guns by the Ampere force was provided with a dielectric insert (3) placed in the region of plasma injection. The dielectric insert (3) forms a drift channel of neutral external plasma of a corresponding diameter specifying its motion direction along force lines of an external magnetic field.

At the absence of the dielectric insert (3) the external plasma radially moving to an axis of the drift chamber forms a planar plasma anode. So, in the accelerator, the formation of the plasma anode in the region between the cathode (1) and virtual cathode (5) was realized. In this case the registered maximum collector REB current coincided in accuracy with the maximum value of the diode current. It means that at REB transporting in the drift chamber with plasma filling the virtual cathode did not appear.

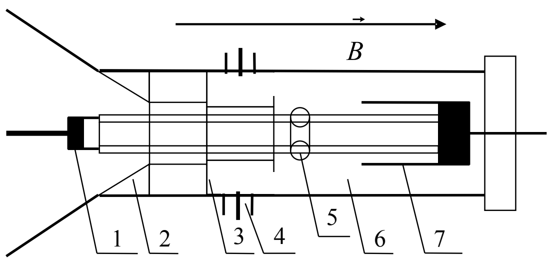

Fig.1. The scheme of the first section of ion accelerator 1 - cathode; 2 - anode; 3 – dielectric insert; 4 – plasma gun; 5 – VC; 6 – drift chamber; 7 – Faraday cup

The application of the dielectric insert (3) has allowed forming the near-wall plasma anode by means of radial injection of plasma. By change of the longitudinal size of the insert the different operational regimes of the virtual cathode were realized. In experiments with a lengthy dielectric insert (3) a pulse of the collector current on the Faraday cup in accuracy corresponded to the pulse of REB at accelerator operation without an external plasma source. When the insert (3) was shorter on the collector current pulse the peak was observed (Fig.2 (3)) whose amplitude was equal to the maximum value of the diode current. It allowed us to make a conclusion that for this short time the virtual cathode has disappeared.

3. LW MODULATION OF REB

In Fig.2 the oscillograms of current pulses of the plasma gun (1), and diode (2), and Faraday cup (3) are shown. The time delay between pulses of cur-

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rents of the plasma gun and diode are chosen so that injection of relativistic electron beam corresponds to the moment of a maximum density of plasma. The peak on the oscillogram of the current of Faraday cup (3) corresponds to short-time disappearance of the virtual cathode due to its charge compensation by plasma ions. The time of 480 ns from the beginning of Faraday cup current pulse to peak appearance is determined by the time of motion of plasma ions from the plasma source to the region of the virtual cathode. The duration of peak corresponds to the time of the virtual cathode disappearance.

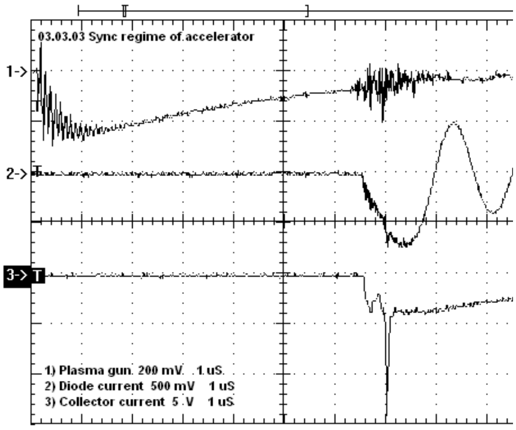


Fig.2. Sync mode of accelerator units

In Fig.3 the oscillograms of diode and Faraday cup currents are shown. The lower oscillogram maps of low frequency temporal modulation of REB current has been obtained with a short length of the dielectric insert (3).

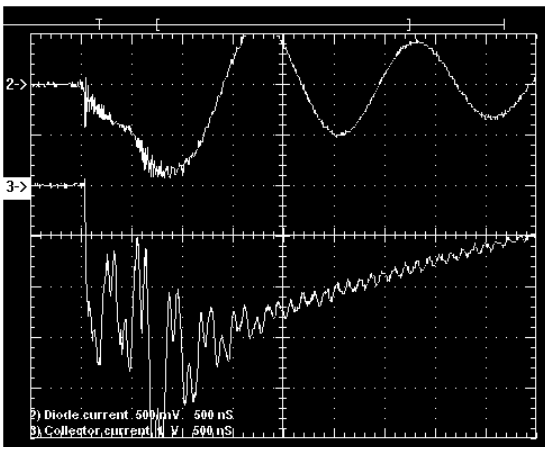


Fig.3. Low frequency modulation of REB

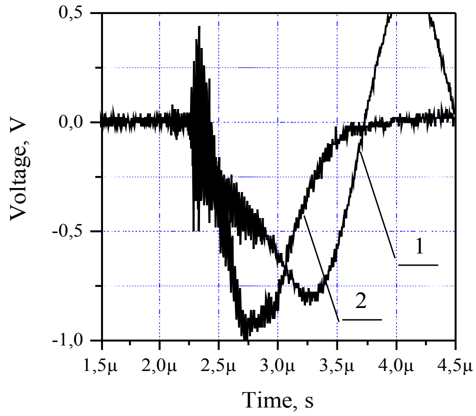
Thus, in the first section of the collective ion accelerator the operation of an external plasma source is realized. The external plasma source serves as a plasma anode.

The applied dielectric insert promotes formation of near-wall plasma anode with radial injection of ions. As the dielectric insert length decreases, the low frequency REB modulation is observed. In the beginning with decreasing of the insert length the frequency REB modulation increases. At dielectric insert length when the straight-line injection from plasma guns along the radius opens and the planar anode is formed the REB modulation is not observed as the virtual cathode disappears.

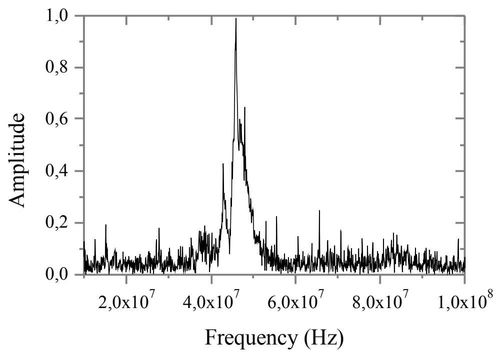
The maximum modulation frequency that was observed in experiments had the value of 46 MHz. And the maximum modulation depth was 10%.

Adding confirmation of the low-frequency REB modulation was the registration of the X-radiation. The REB produced the X-radiation at bombardment of the target from stainless steel. The used registration technique of the X-radiation is shown in paper [1]. The TDS224 oscillograph registered the signal from the sensor of the X-radiation.

In Fig.4 the similar results obtained at the presence of plasma from the external source are shown.



a



b

Fig.4. Pulses of input diode current (1) and X-radiation (2) (a), and spectrum function of X- radiation (b) with external plasma

The duration of REB current was equal to the pulse duration of the X-radiation and had a value ~0.8 μs. In Fig. 4,b the spectrum function of the X-radiation is shown with the maximum in the region of 46 MHz.

4. ENERGY OF IONS ACCELERATED BY A SPACE CHARGE FIELD OF VIRTUAL CATHODE

For determination of kinetic energy of ions, which were previously accelerated by a space charge field of virtual cathode in the first section of an ion accelerator, the method based on motion of a charged particle in transversal magnetic field was used. On paths of transporting of electron and ion beams, the magnet was set with the magnetic induction vector $B_\perp$ perpendicularity to paths of flying particles. Under action of force $m\mathrm{d}v/\mathrm{d}t = q(v\times B_\perp)$, which acts on a moving particle with velocity v and charge q, and mass m, the particle moves along the circle with radius $r = mv/qB_\perp$. After departure from the magnetic field, the charged particles move uniformly and rectilinearly.

The kinetic energy of ions is determined by the relation

$$E = \frac{1}{2m}\left(\frac{\delta L}{l}qB_\perp\right)^2, \qquad (1)$$

where δ is the cross-sectional size of homogeneous magnetic field $B_\perp$; L is the distance between the magnetic field and screen; l is the deflection of the ion from the initial direction, which is registered on the screen. In our experiments the screen was made from the cellulose nitrate that was also the track detector of ion flow.

In our experimental research the deflection system was used with the following parameters: $|B_\perp|$=0.144 T; δ =40 mm; L=40 cm. The slot width of the diaphragm placed before the transversal magnetic field was equal to 1 mm. For singly charged ions of carbon C^+ the deflection l has value 6.08±0.82 mm. Accordingly to (1) the ion energy is obtained $E\approx(0.87\pm0.09)\times10^{-13}$ J (i.e. 0.54±0.06 MeV).

It should be noted that the ion energy (0.54±0.06 MeV) exceeds the electron energy (≈210±30 keV). It is evidence of that the potential well created by the space charge of the virtual cathode in our experiments exceeds the potential of electron beam more than twice.

CONCLUSION

Thus, in the first section of the collective ion accelerator the low-frequency REB modulation and the pre-acceleration of ions were realized using an external plasma source. The ion source was the near-wall plasma anode. The low frequency was determined by the registration of the REB collector current and the X-radiation with calculating its spectrum function. The maximum modulation frequency had the value of 46 MHz. The technique for accelerated ion energy measuring based on the motion of the charged particle in an orthogonal magnetic field was made and used. The measurements of deflection of ions by the magnet system have allowed to determine the energy of singly charged ions of carbon C^+ that amounts (540±60) keV.

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НИЗКОЧАСТОТНАЯ МОДУЛЯЦИЯ РЭП И УСКОРЕНИЕ ИОНОВ В РЕЖИМЕ ЗАКРИТИЧНОСТИ ПРИ ВНЕШНЕЙ ИНЖЕКЦИИ ПЛАЗМЫ

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Экспериментально исследована низкочастотная модуляция сильноточного релятивистского электронного пучка (РЭП) и ускорение ионов в первой секции двухсекционного коллективного ускорителя ионов. Низкочастотная модуляция сверхкритического сильноточного РЭП осуществлена периодической компенсацией виртуального катода ионами плазмы. Ионный поток сформирован электрическим полем виртуального катода. Плазма образована четырьмя плазменными пушками бостиковского типа, расположенными равномерно по периферии камеры дрейфа в области виртуального катода. Модуляция РЭП с глубиной 10% осуществлена на частоте 46 МГц. Энергия ионов измерена с помощью магнитного анализатора. Энергия ионов, которая возможно получена в потенциальной яме виртуального катода, превысила энергию РЭП.

НИЗЬКОЧАСТОТНА МОДУЛЯЦІЯ РЕП ТА ПРИСКОРЕННЯ ІОНІВ В РЕЖИМІ ЗАКРИТИЧНОСТІ ПРИ ЗОВНІШНІЙ ІНЖЕКЦІЇ ПЛАЗМИ

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Експериментально досліджена низькочастотна модуляція сильнострумового релятивістського електронного пучка (РЕП) та прискорення іонів в першій секції двохсекційного колективного прискорювача іонів. Низькочастотна модуляція надкритичного сильнострумового РЕП здійснена періодичною компенсацією віртуального катода іонами плазми. Іонний потік сформований електричним полем віртуального катода. Плазма створена чотирма плазмовими пушками бостіковського типу, розміщеними рівномірно по периферії камери дрейфу в області віртуального катода. Модуляція РЕП з глибиною 10% реалізована на частоті 46 МГц. Енергія іонів виміряна за допомогою магнітного аналізатора. Енергія іонів, яка ймовірно отримана в потенційній ямі віртуального катоду, перевищила енергію РЕП.

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