FORMATION OF A SEQUENCE CHAINS OF NANOSECOND ION BUNCHES FOR INJECTION IN A LINEAR ACCELERATOR

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Currently there are generators of intense ion beams of nanosecond duration. For the purpose of the injection such ions into a linear accelerator the formation of a sequence ~10^2 ion bunches of a duration of 20 ns, a current of ~100 mA total current pulse duration of about 1 μs is considered in this work. In this case, bunches of highly charged ions (HCI) of aluminum are generated by field emission by applying a voltage of 400 kV, a duration of 50 ns at a block of aluminum emitters, spaced along the axis of the injector. The injector consists of a sequence coaxial emitters, a grounded accelerating grid and a retarding-and-turning grid. Trough the retarding-and-turning grid a current is passed from the current pulse generator, which creates an azimuthal magnetic field directing HTI along the axis. The analytical calculations that determine the parameters and confirming the possibility of the technical realization of such a device are shown.

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INTRODUCTION

In [1, 2] experiments are described on the generation of high charged ions (HCI) by applying a pulsed voltage of 300…400 kV and duration of 50 ns to block of edged emitters of aluminum.

In this case high-voltage of positive polarity is introduced into the ion source chamber through the bushing insulator of porcelain. At the end of the high voltage bushing the block of emitters is placed. Further along the axis of the system the extracting grounded electrode is placed. In the experiments the strip emitters of aluminum are used, because of their efficiency and good reproducibility of the results.

Thus the ion beams are formed in a high voltage accelerating diode, the anode of which is represented by the block of edged emitters, and the cathode – by the grid consisting of longitudinal metal wires.

The main investigations have been carried out with a flat block of emitters with area of 16 cm^2. This block has 20 parallel edged emitters of length of 4 cm each. The emitters operate stably over $10^3…10^4$ "shots". Measurements made using the tracking detectors, magnetic analyzer, and other. It was showed that the beams are composed mainly of aluminum ions with a charge Z = 8 ± 1 and the current 30…35 A. In this case, the current of 0.4 A corresponds to the emitter length of 1 cm.

The measurements were shown that, according to theory [3, 4], the generation of high-charge ions is connected with the above-barrier field ionization in super strong pulse electric fields with intensity E that is more than 10^{10} V/cm.

1. THE DEVICE FOR CREATING THE CHAIN OF IONS

For further acceleration of such bunches the device is demanded which generates the chain of ion bunches suitable for insertion into the linear accelerator, i.e. having the current of ~100 mA and pulse duration of ~1 μs. For this purpose the HCI emitters are spaced along the axis of the injector in the device is being described.

In Fig. 1 the scheme of such injector is shown. It consists of the coaxial blocks of emitters 1, the grounded accelerating grid 2, the retarding-and-turning grid 3, and the grounded accelerated electrode 4. On the blocks of emitters the voltage U_1 is applied from the pulse voltage generator (PVG). Through the retarding- and-turning grid 3 it is passed the current I, which creates the turning azimuthal magnetic field from the pulse current generator (PCG). The retarding voltage U_2 is applied to it also. The cylindrical accelerating grounded electrode 4 is placed at the output of the injector.

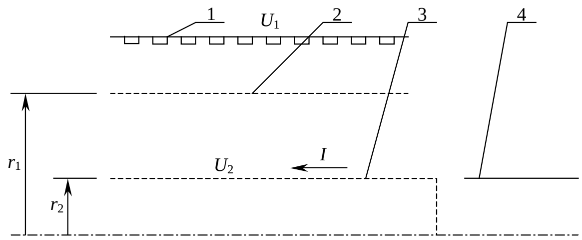

Fig. 1. Diagram of the device to create a chain of ion bunches

The device operates as follows. A voltage pulse is applied to the block of emitters, under the influence of which Z-fold positive ions of metal are pulled out from the emitters and then are accelerated under the influence of the accelerating electric field to the maximum energy equal to ZeU_1. At the same time, while moving in the azimuthal pulsed magnetic field produced by the grid 3, their radial energy begins to pass in the longitudinal energy. However at so high energy (about 400 keV) the Larmor radius of the ions is too big and to completely turn the ions along the system, you need to slow them down to a lower energy (~4 keV). For this purpose, pulse voltage is applied on the retarding-and-turning grid 3 which creates a slowing down electric field between the grids 2 and 3. Under the influence of this field, the ions are decelerated to the energy ZeU_2 and fully turning along the system, get into the drift region within the grid 3. In this region a distance between the ion bunches is equal to a distance between the emitters. Next, the ion beam passes through the accelerating gap between the face of the retarding and turning grid 3 and the accelerating electrode 4, getting into the drift region inside it with the energy equal to ZeU_1. Thus the distance between the ion bunches increases in proportion to the velocity of the beam.

2. CALCULATION OF PARAMETERS OF THE SYSTEM

Let us find the current *I*, which must be passed through the retarding-and-turning grid 3. Let the radii of the accelerating grid and the retarding-and-turning grid are r_1 and r_2, respectively. The accelerating grid is grounded and the retarding-and-turning grid is under the voltage U_2.

The Lagrangian of the system is written as follows:

$$L = \frac{mV_r^2}{2} + \frac{mV_z^2}{2} + \frac{e}{c} V_z A_z - eU. \quad (1)$$

The expression for the scalar potential in the axially symmetric case is [5]:

$$U = U_0 - 2\sigma \ln \frac{r}{r_0}, \quad (2)$$

where σ is a linear charge density. A similar expression can be written for the longitudinal component of the vector potential:

$$A_z = A_{z0} - \frac{2I}{c} \ln \frac{r}{r_0}. \quad (3)$$

Substituting (1) in the Euler-Lagrange equation with (2) and (3) and expressing σ by U_2, we obtain the equations of motion of a charged particle in such a system:

$$r\frac{dV_r}{dt} = \tau - AV_z, \quad (4)$$

$$r\frac{dV_z}{dt} = AV_r, \quad (5)$$

where $A = \frac{2\xi I}{c^2}$, $\tau = -\xi \frac{U_2}{\ln \frac{r_2}{r_1}}$, ξ is a charge to mass ratio, c is a light velocity. Integrating (5) we obtain an expression for the longitudinal velocity of the particle:

$$V_z = A \ln \frac{r}{r_1} + V_{z0}, \quad (6)$$

where V_{z0} is an initial longitudinal velocity of a particle (under $r=r_1$). After the integration of (4) with (6) we obtain the energy conservation law:

$$V_r^2 + V_z^2 - 2\tau \ln \frac{r}{r_1} = V_{r0}^2 + V_{z0}^2, \quad (7)$$

where V_{r0} is an initial radial velocity of a particle (under $r=r_1$). The current *I* must be such that the radial velocity of the particles approached to 0 when $r=r_2$. Assuming $V_r=0$ at $r=r_2$, and also taking into account that $V_{r0}^2 + V_{z0}^2 \equiv V_0^2 = 2\xi U_1$ is the total initial energy of the ion (up to a factor of 2/m) and by entering the initial injection angle α, we find the current which provides a turn of the beam along the axis of the system:

$$I = \frac{c^2}{\sqrt{2\xi}} \frac{\sqrt{U_1 - U_2} - \sqrt{U_1}\cos\alpha}{\ln \frac{r_2}{r_1}}. \quad (8)$$

The initial injection angle α can be set, for example, creating an azimuthal magnetic field in the accelerating gap between the blocks of emitters 1 and the accelerating grid 2. In the absence of the field ($\alpha=-\pi/2$) we obtain:

$$\frac{I}{\sqrt{U_1 - U_2}} = \frac{c^2}{\sqrt{2\xi}\ln \frac{r_2}{r_1}}. \quad (9)$$

Let us estimate the value of this ratio. Let $r_1/r_2 = 3$, $\xi =$

$$l_2 = \frac{V_{z2}}{f}, \quad (13)$$

where f is a frequency of the accelerating field. From here, using (12), we obtain a similar expression for the distance between the bunches within the grid 3:

$$l_1 = \frac{V_{z1}}{f}. \quad (14)$$

Since $V_{z1} = \sqrt{2\xi(U_1 - U_2)}$, then from (11) we finally have:

$$l_1 = \frac{\sqrt{2\xi(U_1 - U_2)}}{f}. \quad (15)$$

Obviously, such a distance should be also between the emitters. When the accelerating field frequency f=100 MHz, l_1=0.63 cm, for generating a train of 100 bunches the total length of the block of emitters must be respectively 63 cm.

Like that, the analytical calculations determine the parameters and confirming the possibility of the technical realization of such a device are shown.

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ФОРМИРОВАНИЕ ПОСЛЕДОВАТЕЛЬНЫХ ЦЕПОЧЕК ИОННЫХ НАНОСЕКУНДНЫХ СГУСТКОВ ДЛЯ ИНЖЕКЦИИ В ЛИНЕЙНЫЙ УСКОРИТЕЛЬ

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В настоящее время имеются генераторы интенсивных ионных пучков наносекундной длительности. С целью инжекции таких ионов в линейный ускоритель в данной работе рассмотрено формирование последовательности ~10^2 ионных сгустков длительностью 20 нс, током ~100 мА в суммарный токовый импульс длительностью ~1 мкс. При этом сгустки высокозарядных ионов алюминия (ВЗИ) генерируются автоэмиссионным путем при подаче напряжения 400 кВ, длительностью 50 нс на блок острийных эмиттеров из алюминия, разнесенных в пространстве вдоль оси инжектора. Инжектор состоит из коаксиально расположенных эмиттеров, заземленной ускоряющей сетки и замедляюще-поворотной сетки. Через замедляюще-поворотную сетку пропускается ток от генератора импульсного тока, создающий азимутальное магнитное поле, направляющее ВЗИ вдоль оси. Приведены аналитические расчеты, определяющие параметры и подтверждающие возможность технической реализации подобного устройства.

ФОРМУВАННЯ ПОСЛІДОВНИХ ЛАНЦЮЖКІВ ІОННИХ НАНОСЕКУНДНИХ ЗГУСТКІВ ДЛЯ ІНЖЕКЦІЇ В ЛІНІЙНИЙ ПРИСКОРЮВАЧ

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Наразі є генератори інтенсивних іонних пучків наносекундної тривалості. З метою інжекції таких іонів у лінійний прискорювач у цій роботі розглянуто формування послідовності ~10^2 іонних згустків тривалістю 20 нс, струмом ~100 мА в сумарний струмовий імпульс тривалістю ~1 мкс. Згустки високозарядних іонів алюмінію (ВЗІ) генеруються автоемісійним шляхом при подачі напруги 400 кВ, тривалістю 50 нс на блок вістрійних емітерів з алюмінію, рознесених у просторі уздовж осі інжектора. Інжектор складається з коаксіально розташованих емітерів, заземленої прискорюючої сітки і сповільнюючо-поворотної сітки. Через сповільнюючо-поворотну сітку пропускається струм від генератора імпульсного струму, що створює азимутальне магнітне поле, яке спрямовує ВЗІ уздовж осі. Наведені аналітичні розрахунки, що визначають параметри й підтверджують можливість технічної реалізації подібного пристрою.