AN ACCELERATING&FOCUSING STRUCTURE WITH COMBINED RF FOCUSING FOR HEAVY ION ACCELERATOR

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An accelerating&focusing channel of high-current linac for heavy ions with mass-to-charge ratio $A/q \leq 20$ is presented. The channel is calculated to form and accelerate an ion beam from 6 keV/nucl. up to 1 MeV/nucl. An accelerator initial part based on a RFQ that provides acceleration from 6 to 100 keV/nucl. and a pre-stripping section with combined RF focusing for final acceleration up to 1 MeV/nucl. comprises the accelerating-focusing channel. It is proposed to use an IH structure for combined focusing. Numerical simulation of beam dynamics is performed. The channel allows ion beam acceleration at currents up to 10 mA.

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INTRODUCTION

One of the fields of application of ion accelerators is associated with research in safety of nuclear power engineering. An investigation of the processes of radiation influence on plastic characteristics of nuclear power plant construction materials provides an example of accelerated charged particle application.

It is suggested to use the multicharged ion linac (MILAC) of the NSC KIPT to address this issue. However, the MILAC pre-stripping section at its present state realizes grid focusing and as a consequence provides charged particle beams of low current. Replacing grid focusing with focusing by electromagnetic quadrupole lenses placed inside a drift tube runs into the following obstacle. At the present time electromagnetic lenses evolve into rather complex technological units of accelerator with their own power supply and cooling systems. Besides, as focusing rigidity obtained by an electromagnetic quadrupole lens is proportional to particle velocity, it is necessary to use strong lenses for heavy ion beams in a range of low energy value and in the process there arises a problem of how to fit such a large lens into a short drift tube that corresponds to the small relative velocity β. Because of this, it is very important to develop a concept of heavy ion beam acceleration and focusing which on the one hand is simple in design and on the other hand provides sufficient focusing rigidity to yield an increase in accelerated current value. From our standpoint, the choice of combined RF focusing method is rather promising [1]. By using this type of focusing, we could simplify the accelerating structure reasonably and provide wanted focusing rigidity for high-current heavy ion beam acceleration without the use of any external focusing devices.

The main objective is to show the possibility of introducing the accelerating&focusing channel into the pre-stripping section of high-current heavy ion linac based on an interdigital H type structure (IH structure) with combined RF focusing.

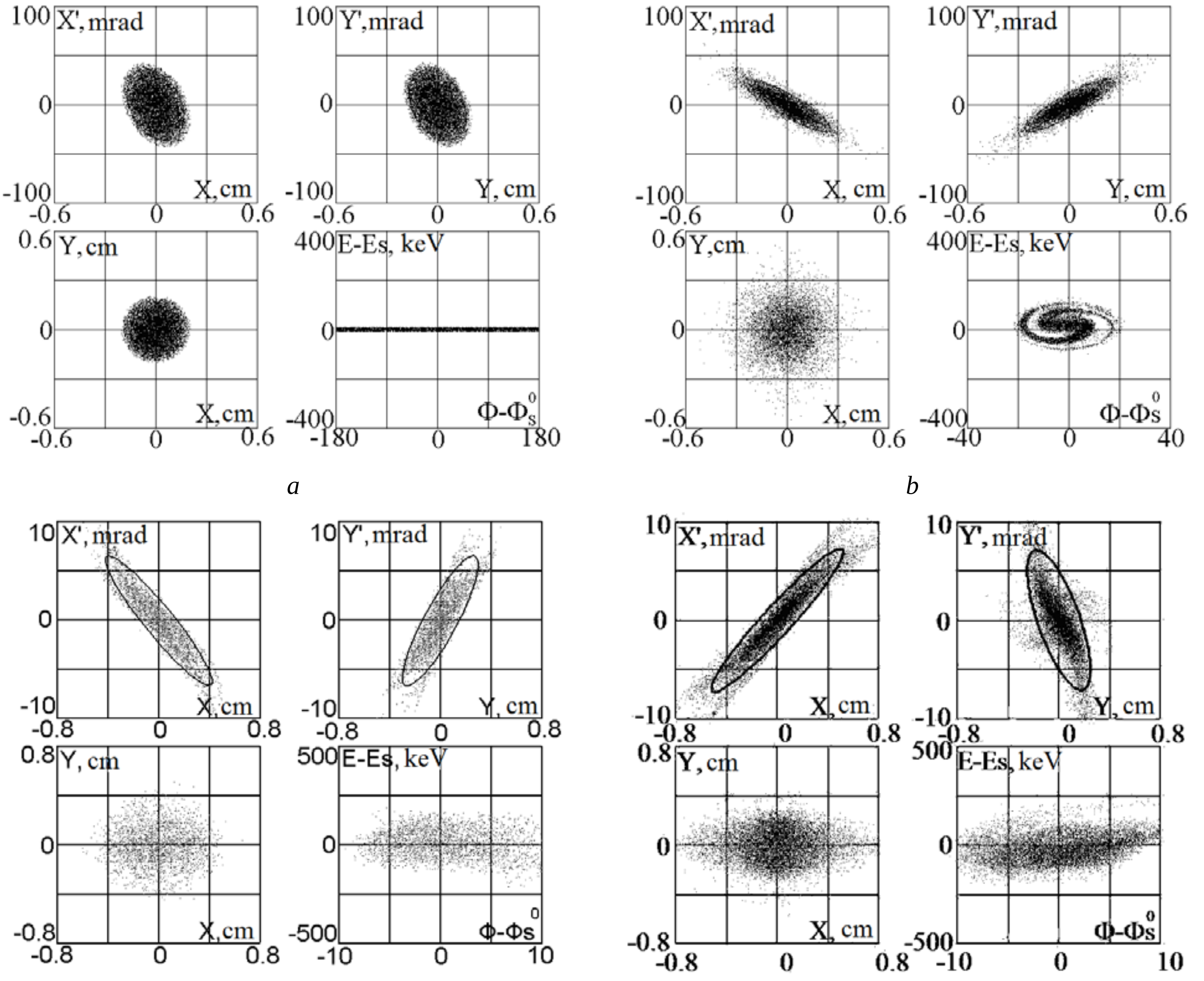
1. A PRE-STRIPPING SECTION OF THE HEAVY ION LINAC WITH RF FOCUSING

At present the multicharged ion linac of the NSC KIPT is used for acceleration of ions with mass-to charge ratio $A/q \leq 15$. The linac is composed of (1) a high-voltage injector (with energy up to 30 keV/u), (2) a pre-stripping section POS-15 that implements grid focusing and yields output energy up to 0.975 MeV/u, and (3) a main section OS-5 with the magnetic quadrupole lens. On entering the main section after leaving the POS-15 part, ions to-be-accelerated travel through a thin carbon film to increase their mass-to-charge ratio up to $A/q \leq 5$. Output energy at the end of the main section ranges up to 8.5 MeV/u.

As indicate above, the section with grid focusing sets limits on accelerating current and reduces the accelerator reliability. Besides, there exist some difficulties in operating the high-voltage injector. In Ref.[2] an alternative MILAC pre-stripping section is presented. It consists of (1) a low-voltage injector, (2) RFQ structure, and (3) a section with combined RF focusing.

The main characteristics of the section with combined RF focusing are as follows. The accelerating structure is of IH type; operating frequency is 47.2 MHz; there are 143 accelerating periods; the electrodes measure 3 m in length. Fig. 1,a represents the following input beam parameters: the transverse beam emittances (normalized rms emittance $\varepsilon_{x,y}(rms)=0.05$ mm·mrad, normalized emmitance that involves 100% of a beam to-be-accelerated $\varepsilon_{x,y}(100\%)=0.3$ mm·mrad), the beam geometric projection on the XY plane and the beam phase portrait. Injection energy is $W_0=6$ keV/u. To simulate the accelerating&focusing channel of the accelerator main part with combined RF focusing and beam dynamics within it, the APFRFQ program is used [1]. The initial number of macroparticles for beam dynamics simulation with regard to space charge forces is 10000. Fig. 1,b shows the output beam parameters ($\varepsilon_x(rms)=0.092$ mm·mrad, $\varepsilon_y(rms)=0.090$ mm·mrad) calculated at injection current 13.3 mA and energy yield 100 keV/u. It is worthy of note that about 75% of beam bulk is captured in acceleration process (input current being 10 mA). If injection current is absent, much more beam particles (about 89%) are captured in acceleration. As this takes place, output energy reaches 1 MeV/u.

Further acceleration takes place in the accelerating&focusing channel that implements combined RF focusing. Fig. 1,c depicts the output beam parameters ($\varepsilon_x(rms)=0.110$ mm·mrad, $\varepsilon_y(rms)=0.111$ mm·mrad) calculated at initial current 10 mA and output energy 1 MeV/u. The focusing period structure features FOOODDOOOF pattern, where F is an accelerating period with a focusing quadrupole in a transverse direction (for instance, X if XYZ are Cartesian coordinates and Z is the beam propagation direction), D denotes a defocusing period in the same direction, O represents an axisymmetrical accelerating period. There are 83 accelerating gaps in the accelerating&focisung channel of total length of 792 cm.



a

b

c

d

Fig. 1. Beam parameters for heavy ion linac with RF focusing: a – on entrance to the RFQ structure; b – on exit from the RFQ structure; c – on exit from the structure with combined RF focusing, the length of a focusing gap being 5/2 βλ; d – on exit from the structure with combined RF focusing, the length of a focusing gap being 7/2 βλ

The channel allows lossless current acceleration up to 20 mA. The total length of the pre-stripping section including the structure with combined RF focusing is 11 m. The length can be reduced by increasing the number of the axisymmetrical accelerating gaps that leads to elongation of the focusing period with combined RF focusing. Thus, the pattern of the structure becomes FOOOOODDOOOOOF. In this case the number of accelerating gaps is 63 reducing the channel length to 593 cm. The total length decreases down to 9 m. Accelerating current reaches 9.38 mA. Fig. 1,d presents calculated output beam parameters (ε_x(rms)=0.170 mm·mrad, ε_y(rms)=0.173 mm·mrad) computed at initial current 10 mA and output energy 1 MeV/u.

There are several ways to construct a segment with combined RF focusing. One of them is by using two IH sections with 5 and 4 focusing periods, respectively (Fig. 2,a), an alternative is to use only one IH section with 9 periods for focusing.

The accelerating IH structure with spatially homogeneous quadrupole focusing for heavy ion acceleration UNILAC has been developed, constructed and already put into action in Germany [3]. In terms of design, the IH structure under consideration is different from the UNILAC one. Using MILAC last section of the prestripper as an example, let us look more closely at the IH structure.

2. DESIGN FEATURES AND TUNING OF THE IH STRUCTURE WITH COMBINED RF FOCUSING

There is a very effective way to control the electric field distribution of the IH structure. It is based on the usage of end resonant adjustment elements (ERAE) which exist in a variety of constructional designs. In our case if the structure provides combined RF focusing, field tuning calls for a specific approach. The most acceptable design is shown on Fig. 2,a,b. As indicated in the picture, first and last two (or three) drift tubes in a row are placed on one lengthwise load-bearing element with one supporting shaft (there also could be two supporting shafts - each on either end of the structure). The end-cuts are connected to the resonator side surface through conductive mobile pistons with their location being subject to adjustment. This tuning element as an effective tool to control the general electric field distribution in a resonator should be kept mobile in a real situation because the simulations do not often allow obtaining sufficient tuning accuracy and accounting for all possible design deviations.

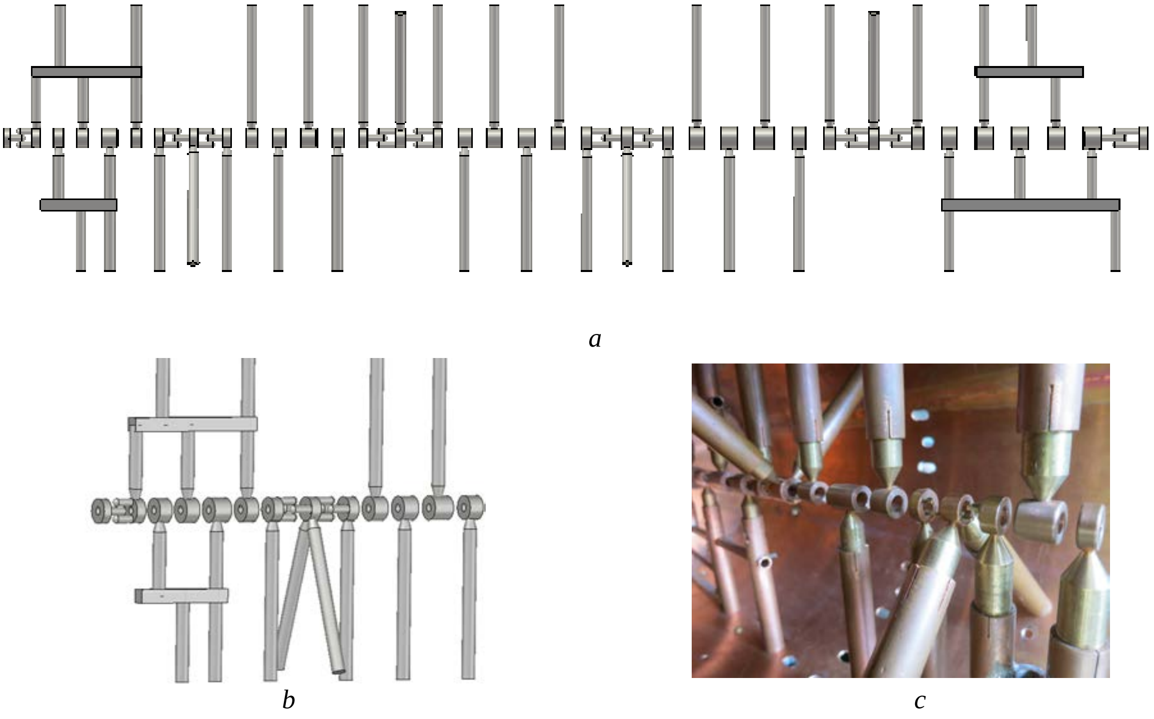


Fig. 2. The IH-structure with combined RF focusing: a, b – schematic view; c – experimental stand

A focusing period in the case of combined RF focusing operates effectively only if there is a possibility of doublet cells' adjustment resulting in generation of a weaker electric field in comparison to the electric field in adjacent accelerating cells since a potential difference between so-called "horns" is directly proportional to the distance between them, but a focusing gradient varies as the reciprocal of the radius squared. Because of this, it is necessary to maintain the potential difference between the "horns" at a constant value along the structure with a constant drift tube aperture. Then the high acceleration rate could be attained only by separate tuning of the focusing and accelerating cells.

An effective way for local tuning of the interdigital structure cell is a method of flexible opening angle of opposite drift tube suspensions. In the case of combined RF focusing, the electric field distribution could be controlled by a change in an angle between two symmetric drift tube suspensions that form a radio-frequency quadrupole doublet (RFQD) (see Fig. 2,b).

As an experimental stand for cell tuning to obtain given electric field distribution by the method of flexible opening angle has been used an accelerating structure of 17 gaps with RFQD-es formed in the 4th and 5th, and 9th and 10th gaps [4].

As a result of investigations it has been found that the electric field level is considerably lowered in the 4th and 5th, and 9th and 10th gaps while in the adjacent gaps it is reduced only slightly. At the same time, some balancing by lowering in general field level takes place in the initial part of the structure where the "accelerating" gaps are present, with a modest increase in field level by the end of the system where the "focusing" cells are absent. In other words, the electric field exhibits some tilt with respect to its initial distribution. Such balancing of the electric field distribution in the "accelerating" gaps placed between "focusing" ones is favorable for long structures with several RFQD-es. The electric field in the adjacent gaps could be controlled by drift tube diameters while the general inclination in the electric field distribution – by positioning the ERAE pistons.

All investigations have been carried out on the experimental stand with the use of a measuring complex that allows studying electrodynamical characteristics such as frequency, electric field strength, Q-factor, shunt resistance, etc, of resonant accelerating structures. Electric field parameters have been obtained by a well-known small disturbance method [5].

CONCLUSIONS

The feasibility of a high-current channel in a heavy ion linac implementing combined RF focusing on a basis of IH structures has been verified experimentally. The usage of combined RF focusing allows considerable simplification in the accelerating structure and provides wanted focusing rigidity of a high-current ion beam without external focusing facilities.

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РАЗРАБОТКА УСКОРЯЮЩЕ-ФОКУСИРУЮЩИХ СТРУКТУР С КОМБИНИРОВАННОЙ ВЫСОКОЧАСТОТНОЙ ФОКУСИРОВКОЙ ДЛЯ УСКОРИТЕЛЕЙ ТЯЖЕЛЫХ ИОНОВ

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Рассмотрен ускоряюще-фокусирующий канал сильноточного линейного ускорителя тяжелых ионов с отношением массового числа к зарядовому $A/q \leq 20$. Канал рассчитан на формирование и ускорение пучка от энергии 6 кэВ/нукл. до 1 МэВ/нукл. Функционально в состав канала входит НЧУ на базе ПОКФ (энергия от 6 до 100 кэВ/нукл.) и предобдирочная секция (энергия до 1 МэВ/нукл.) с комбинированной высокочастотной фокусировкой. Предложена схема реализации этого типа фокусировки на базе IH-структур. Проведено численное моделирование динамики пучка. Канал позволяет ускорять пучки ионов с током до 10 мА.

РОЗРОБКА ПРИСКОРЮВАЛЬНО-ФОКУСУВАЛЬНИХ СТРУКТУР З КОМБІНОВАНИМ ВИСОКОЧАСТОТНИМ ФОКУСУВАННЯМ ДЛЯ ЛІНІЙНИХ ПРИСКОРЮВАЧІВ ВАЖКИХ ІОНІВ

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Розглянуто прискорюючо-фокусуючий канал сильнострумового лінійного прискорювача важких іонів з відношенням масового числа до зарядового $A/q \leq 20$. Канал розраховано на формування та прискорення пучків від енергії 6 кеВ/нукл. до 1 МеВ/нукл. Функціонально до складу каналу входить ПЧП на базі ПОКФ (енергія від 6 до 100 кеВ/нукл.) та секція (енергія до 1 МеВ/нукл.) з комбінованим ВЧ-фокусуванням. Запропоновано схему реалізації даного типу фокусування на базі IH-структур. Проведено чисельне моделювання динаміки пучків. Канал дозволяє прискорювати пучки іонів зі струмом до 10 мА.