REGULATION OF LEVEL RF-FIELDS IN HYBRID STRUCTURES OF HEAVY IONS LINEAR ACCELERATORS

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The new prestripping section of the heavy ions linear accelerator with mass-to-charge ratio $A/q \leq 20$, allowing to accelerate ions from 6 keV/u to energy of 1 MeV/u is developed. The section represents a combination of diverse accelerating structures in one cavity: with radio frequency quadrupole focusing (RFQ) and structure with drift tubes (DTL). In contrast to conventional acceleration systems, the use of the more compact hybrid cavity simplifies system operation due to their coupled complex acceleration electrode and integrated peripheral devices, such as their power and vacuum systems. However thus distribution RF-field in such structure and its frequency characteristics essentially changes. It is shown that using tuning devices: tuners, end resonant, inductive and capacitive elements in such structure it is possible to provide require frequency and uniform distribution of electric field in an accelerating path of the hybrid cavity.

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INTRODUCTION

The multicharging ions linac MILAC is used for acceleration ions with $A/q \leq 15$. Structurally into its composition enter: a high-voltage injector (output energy 30 keV/u), prestripping section PSS-15 with grid focusing (output energy 0.975 MeV/u) and the main section MS-5 with focusing by magnetic quadrupole lenses (output energy 8.5 MeV/u). Heavy ions after PSS-15 transit through a thin carbon film where their charge is incremented to $A/q \leq 5$ and accelerated in the main section to energy 8.5 MeV/u.

Presence of section with grid focusing essentially restricts quantity of an accelerated current and reduces reliability of the accelerator. Besides, operation of a high-voltage injector presents certain difficulties.

Now in NSC KIPT the new prestripping section PSS-20 ($A/q = 20$) is developed, which allows to dilate considerably a gamut of masses accelerated ions, to increment quantity of an accelerated current and considerably to lower energy of injection. It is reached thanks to two types of accelerating structures: to structure with radio frequency quadrupole focusing (RFQ) [1, 2, 3], and structure with drift tubes (DTL).

The continuous beam leaving an injector, in structure with RFQ is grouped in compacted bunch practically loss-free. A deficiency of the given structure is low rate of acceleration. Therefore, since energies 2…3 MeV, already the bunched beam is accelerated further in structure with drift tubes (DTL). In Fig. 1,a, the classical scheme construction of an initial part of the accelerator is presented. Structure with RFQ and structure with drift tubes are located in separate resonators between which the matching line is located.

More compacted, a hybrid scheme of an initial part accelerator is offered. The prestripping section PSS-20 represents a combination of two diverse IH structures (Interdigital H-type structure): RFQ and structure with drift tubes DTL in one resonator (Fig. 1,b).

Unlike a traditional variant, placement of two structures in one resonator does by more compacted prestripping part of the accelerator and considerably simplifies a control system peripheral to devices, such as vacuum system and system RF-power.

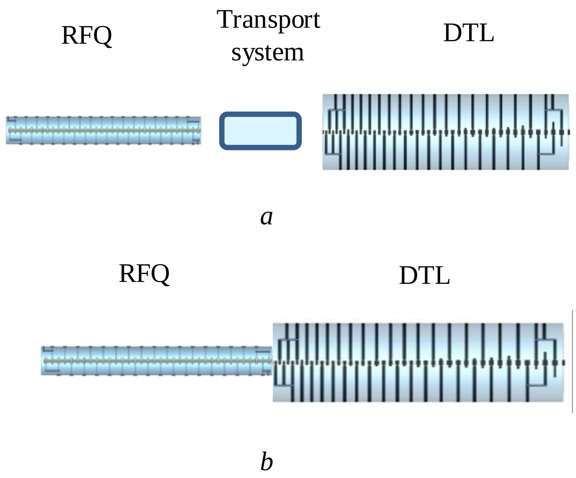

Fig. 1. The scheme of initial site of the accelerator: a – the classical; b – the hybrid

That hybrid structures are offered for protons [4] ($A/q = 1$) and for carbon ions C^{6+} [5] ($A/q = 2$). The length of these structures is comparatively small. However, in such structures process of adjustment of the resonator on operational frequency and amplitudes RF-field along an accelerating path essentially complicated.

In this research possibility is presented and the procedure of adjustment of performances RF-field is offered in extended hybrid structure (~ 9 m) for acceleration of heavy ions ($A/q \leq 20$) and output energy 1 MeV/u.

1. THE BASIC ADJUSTING DEVICES

The adjustment procedure consists in the following. Amplitude RF-field and operating frequency is attuned separately in the resonator with RFQ and in the resonator with drift tubes. Then these two resonators unite in one section. Changed values of characteristics RF-field along an accelerating path and value of operating frequency of the combined structure are arranged by adjusting devices. Basic elements of adjustment of parametres prestripping section are presented in Fig. 2.

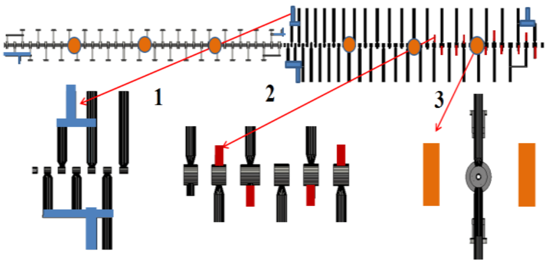

Fig. 2. The scheme hybrid prestripping section of a heavy ions linac (the cavity not shown) and adjusting devices: 1 – the end resonant tuning element; 2 – the inductive and capacitive tuning element; 3 – the tuner

Each adjusting device carries out certain function.

1. The end resonant tuning element [6]. It is intended for global adjustment of an electric field in the resonator.
2. Inductive and capacitive tuning element. It is intended for local adjustment of an electric field, for example, in an accelerating gap [7, 8].
3. The tuner allows to regulate levels RF-field between various accelerating structures in one resonator and to arrange operating frequency.

2. THE DYNAMIC MATCHING OF THE EMITTANCE OF THE BEAM IN HYBRID STRUCTURE

Let's stop on a following important question: the dynamic matching of a traversal emittance of a beam on output from structure with RFQ and structure with drift tubes. The problem consists in the following. In Fig. 3 beam emittances on various paths of the combined structure are given. On input of structure with RFQ the axisymmetric convergent beam arrives (see Fig. 3,a), on output from RFQ a beam has quadrupole symmetry (see Fig. 3,b) and on input of structure with drift tubes the beam should be again axisymmetric (see Fig. 3,c) [9, 10, 11, 12].

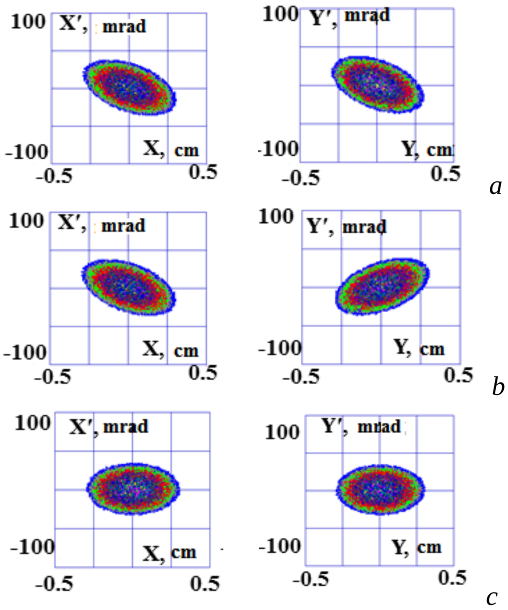

Fig. 3. Traversal emittances of beam on various paths of acceleration in hybrid structure: input in structure with RFQ (a); output from RFQ (b); input in structure with drift tubes (c)

Acceptance the channel of structure with RFQ is not stationary and rotates with frequency RF-field. For the matching of an emittance of the axisymmetric beam leaving from injector with the acceptance structure with RFQ the bell is used. In the bell the quadrupole component of an electric field in accelerating path gradually accrues from zero to value in the regular part RFQ.

In Fig. 4 evolution of the normalised beam envelope on matching path for various values of input phases is presented. Beam envelope are gained as a result of the solution equation for a traversal motion of a beam in structure with RFQ [13] without forces of a volume charge for not modulated structure. Apparently from Fig. 4 application of an accruing quadrupole field allows to transform an input of the axisymmetric beam to a beam with quadrupole symmetry practically without growth of emittance for all gamut of input phases (2π).

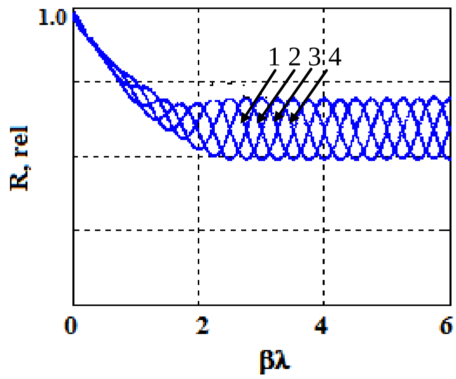

Fig. 4. Evolution of beam envelope on path of the traversal matching for various values of input phases: 1 – - π; 2 – - π/2; 3 – 0; 4 – π/2

For formation of the axisymmetric beam to a beam with quadrupole symmetry on output from structure with RFQ it is possible to arrive on the contrary, having made a quadrupole field waning, from the peak value to the zero. And as a result of acceleration in structure with RFQ phase extent of the bunch considerably decreases (with 360º to ~ 30º). The fact of phase compression of the bunch allows considerably to reduce a path of transformation of the emittance the beam. For this purpose between two interdigital H-type structures dispose a stem at angle 90° (Fig. 5). We will score that thus changes longitudinal component of accelerating field, therefore it is necessary to change length matching path for the longitudinal matching beam with a glance the changed field.

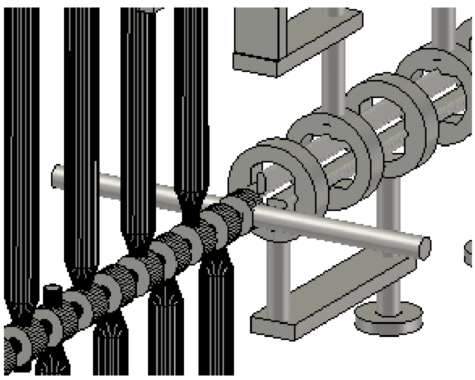

Fig. 5. The scheme of matching RF-fields of structure with RFQ and structure with drift tubes in one resonator

3. THE METHOD ADJUSTMENT RF-FIELD IN HYBRID STRUCTURE OF IONS LINACS

Let's part adjustment RF-field in hybrid structures on some stages.

At the first stage carry out adjustment of structure with RFQ and structure with drift tubes in separate resonators.

The section with RFQ (Fig. 6,a) is calculated on acceleration the ions beam with intensity 10 mA, the mass-to-charge ratio $A/q \leq 20$, energy from 6 to 150 keV/u. Operating frequency is 47.2 MHz. The length of the resonator is 451 cm, diameter – 50 cm. Medial radius of the accelerating channel 0.75 cm. Modelling of electrodynamic parametres was spent on the 1:3 scaled model. Electrodes were used not modulated. Electrical field it was measured between two adjacent electrodes. Apparently from Fig. 6,b allocation electric field between the adjacent quadrupole electrodes along an accelerating path is uniform.

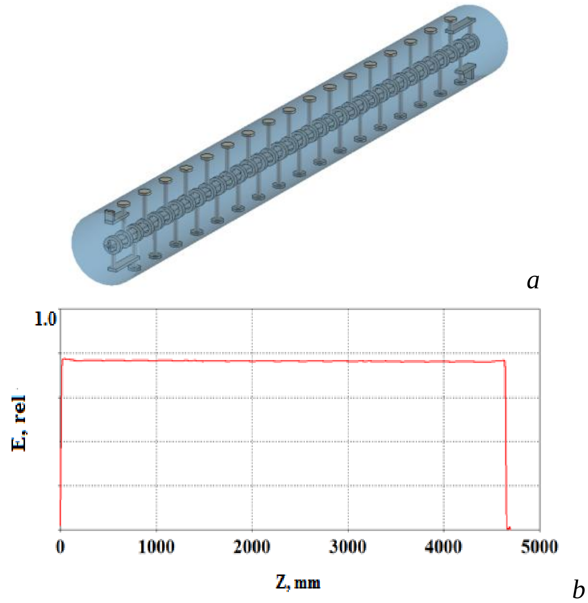

Fig. 6. Section with RFQ (a) and distribution of amplitude RF electric field between adjacent electrodes (b)

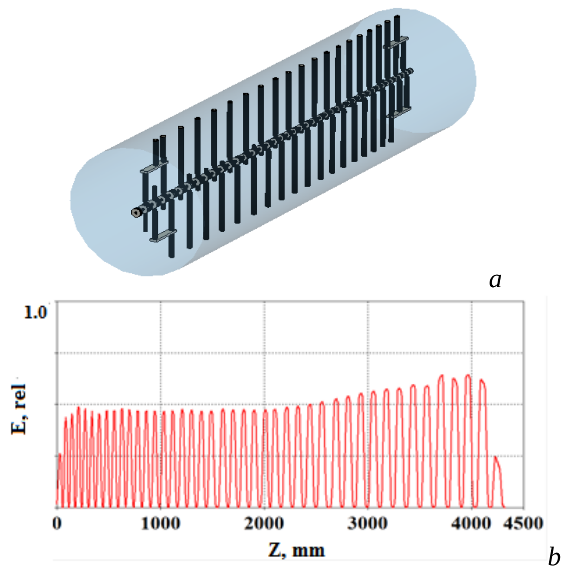

Fig. 7. Section with drift tubes (a) and distribution of amplitude RF electric field on structure axis (b)

The section with drift tubes (Fig. 7,a) is intended for the further acceleration of ions beam with higher rate of acceleration. Rate of acceleration in structure with RFQ is 0.75 MeV/m, in structure with drift tubes – 2.9 MeV/m. The gamut of energies from 150 keV/u to 1 MeV/u. The resonator length is 423 cm, diameter – 110 cm, number of accelerating cells – 42. Apparently from Fig. 7,b allocation of an electric field to axes of the accelerating path rather uniform.

At a following stage two structures unite in one resonator. Also are attuned by means of end resonant tuning element (ERTE). As an example activity ERTE is shown in Fig. 8, 9. In Fig. 8,a,b is shown allocation electric field to axes in the coupled accelerating structure when in ERTE there is no the mobile crosspiece. In Fig. 9,a,b is shown allocation electric field adjusted by means of its element of adjustment – the mobile crosspiece.

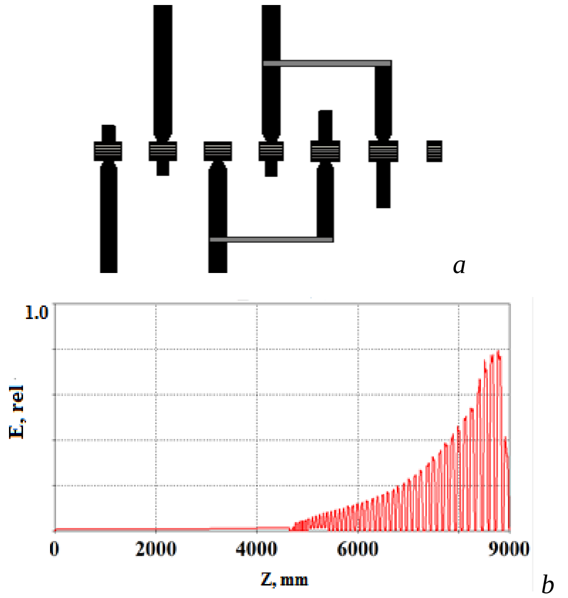

Fig. 8. The path of hybrid structure with ERTE without the mobile crosspiece (a) and distribution of amplitude RF-field (b)

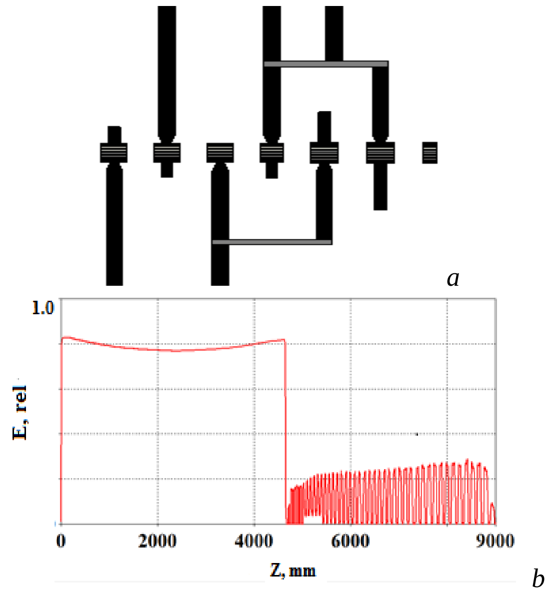

Fig. 9. The path of hybrid structure with ERTE with the mobile crosspiece (a) and distribution of amplitude adjusted RF-field (b)

Definitive adjustment – alignment of amplitudes RF-field in the coupled structure – is carried out with the help tuners. In Fig. 10,a,b it is visible that introduction the tuner in structure with RFQ allows to change effectively the relation of amplitudes RF-field in different resonators, thus the configuration of the field in resonators does not change.

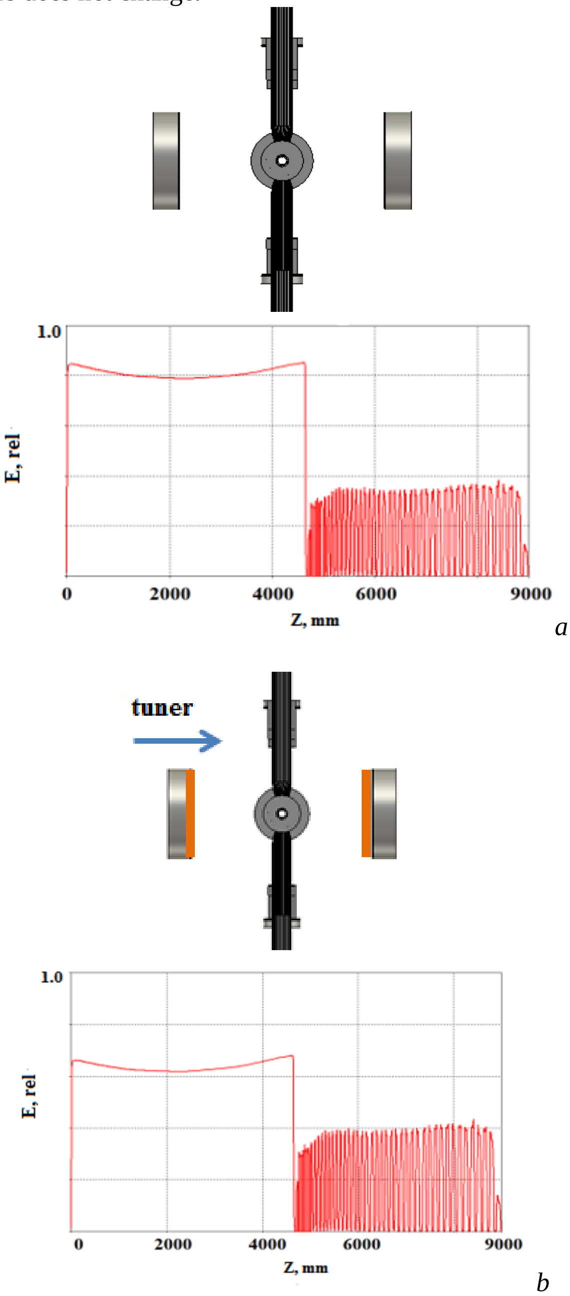

Fig. 10. Distribution of amplitude RF electric field in hybrid structure for two standings tuners: length tuners 50 mm (a); length tuners in structure with RFQ – 60 mm, in structure with drift tubes – 50 mm (b)

CONCLUSIONS

It is shown that using tuning devices: tuners, end resonant, inductive and capacitive elements in the extended hybrid resonator, consisting of diverse structures, it is possible to provide demanded operating frequency and the given distribution of an electric field along accelerating path.

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РЕГУЛИРОВКА УРОВНЯ ВЧ-ПОЛЕЙ В ГИБРИДНЫХ СТРУКТУРАХ ЛИНЕЙНЫХ УСКОРИТЕЛЕЙ ТЯЖЁЛЫХ ИОНОВ

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Разработана новая предобдирочная секция ускорителя тяжёлых ионов с отношением массового числа к зарядовому A/q ≤ 20, позволяющая ускорять ионы от 6 кэВ/нукл. до энергии 1 МэВ/нукл. Секция представляет собой комбинацию разнородных ускоряющих структур в одном резонаторе: с пространственно-однородной квадрупольной фокусировкой и структурой с трубками дрейфа. В отличие от обычных систем ускорения, использование более компактного гибридного резонатора упрощает систему управления благодаря их связанному комплексу ускоряющих электродов и интегрированных периферийных устройств, таких как системы питания и вакуумная. Однако при этом существенно меняется распределение ВЧ-поля в такой структуре и её частотные характеристики. Показано, что, используя настроечные устройства: тюнеры, концевые резонансные, индуктивно-ёмкостные элементы, в такой структуре можно обеспечить требуемую частоту и равномерное распределение электрического поля в ускоряющем тракте гибридного резонатора.

РЕГУЛЮВАННЯ РІВНЯ ВЧ-ПОЛІВ У ГІБРИДНИХ СТРУКТУРАХ ЛІНІЙНИХ ПРИСКОРЮВАЧІВ ВАЖКИХ ІОНІВ

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Розроблено нову передобдіркову секцію прискорювача важких іонів з відношенням масового числа до зарядового A/q ≤ 20, що дозволяє прискорювати іони від 6 кеВ/нукл. до енергії 1 МеВ/нукл. Секція являє собою комбінацію різнорідних прискорюючих структур в одному резонаторі: з просторово-однорідним квадрупольним фокусуванням і структурою з трубками дрейфу. На відміну від звичайних систем прискорення, використання більш компактного гібридного резонатора спрощує систему управління завдяки їх пов’язаному комплексу прискорювальних електродів та інтегрованих периферійних пристроїв, таких як системи живлення й вакуумна. Однак при цьому істотно змінюється розподіл ВЧ-поля в такій структурі та її частотні характеристики. Показано, що, використовуючи настроювальні пристрої: тюнери, кінцеві резонансні, індуктивно-ємнісні елементи, в такій структурі можна забезпечити потрібну частоту та рівномірний розподіл електричного поля в прискорюючому тракті гібридного резонатора.