COUPLING OF PARTS ACCELERATING STRUCTURES RFQ AND DTL IN ONE RESONATOR PRESTRIPPING SECTION THE HEAVY ION LINEAR ACCELERATOR MILAC

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New pre-stripping section (PSS-20) consists of two parts with diverse accelerating structures. On an initial part of acceleration of ions from 6 up to 150 keV/nucl. high capture in process of acceleration of the injected ions is provided interdigital (IH) accelerating structure with Radio-Frequency Quadrupole (RFQ) focusing. On the second part of acceleration of ions from 150 keV/nucl. up to 1 MeV/nucl. the highest rate of acceleration is created interdigital (IH) accelerating structure DTL. The problem of diverse accelerating structures combination in one resonator is set.

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INTRODUCTION

The heavy ion linear accelerator MILAC has started to operate in 1958. Throughout the next years on it were carried out scientific and applied researches on a nuclear physics of heavy ions. On the basis of new achievements to fields of physics and technics of linacs were constantly spent reconstruction accelerator systems. In this time almost all basic systems of the accelerating complex MILAC have been exchanged or reconstructed. The most important were operations on replacement of accelerating structures Alvarez type (E_{010}-wave) on the developed interdigital (IH) accelerating structure (H_{110}-wave) [1, 2, 3]. Feature interdigital (IH) accelerating structure was possibility of magnification of a working wave length three times, from 2.12 m to 6.36 m and magnifications of rate of acceleration twice. Thus the length of the main section of MS-5 of accelerator MILAC was reduced with 18 m to 12 m at the almost same output energy of the accelerated ions 8.5 MeV/nucl. The quantity of drift tubes the main section has decreased with 100 to 40, and the length of new drift tubes has allowed to dispose in them focalizing electromagnetic quadrupole lenses [4]. A new prestripping section PSS-15 has been created that has allowed to extend a range of ions with mass to charge ratio $A/q \leq 15$ [5]. The new system of injection calculated on formation of more intensive beams of heavy ions with energy 30 keV/nucl., arriving on prestripping section PSS-15 has been created. New high-frequency generators with pulse power more 3 MW, and also a new control system have been created.

Now heavy ion linear accelerator MILAC allows to accelerate ions He^+, N^+, Ne^{2+}, Ar^{3+} and other ions with mass to charge ratio $A/q \leq 15$. After acceleration in prestripping section PSS-15 to energy 975 keV/nucl. ions are exposed to stripping on a thin carbon film, their charge is incremented and heavy ions are accelerated in the main section MS-5 to energy 8.5 MeV/nucl. Intensity accelerated to such energies of ions beams makes $10^9 \ldots 10^{10}$ p/s and essentially decreases for ions with mass number $A > 50$.

The problem of making new prestripping section PSS-20 which will allow to dilate considerably a gamut of masses of accelerated ions is put and to increment by two orders intensity of a current of the accelerated ions beams, before $10^{12} \ldots 10^{13}$ p/s. For the solution of this problem it is supposed to use a variant of coupling of two diverse accelerating sites RFQ and DTL in one resonator. It will give the chance to simplify a construction prestripping section and considerably to lower cost PSS-20 at the expense of use of the available equipment and the existing restricted areas, and as considerably to simplify manufacturing and operation new prestripping section PSS-20.

MAIN PARAMETERS OF SITES OF ACCELERATING STRUCTURES RFQ AND DTL FOR PRESTRIPPING SECTION PSS-20

As a result of investigations on working out of accelerating structure new prestripping section PSS-20 for linac MILAC are created backgrounds for its construction. The design procedure of parametres of two sites interdigital (IH) accelerating structure, based on Radio-Frequency Quadrupole focusing (RFQ) and structure with drift tubes (DTL) is developed. These two structures provide both effective formation of heavy ions beams and high rate of acceleration, that will allow on the existing area with restricted length nearby 9 m to accelerate heavy ions with mass to charge ratio $A/q \leq 20$ to energy 1 MeV/nucl.

On the basis of the created procedures and new programs calculations of geometrical and electrodynamic parameters for PSS-20 are executed. Optimisation of the basic performances of accelerating structure taking into account concrete requirements of its construction is executed. In the course of calculations of a site accelerating structure RFQ such parameters, as efficiency of acceleration T_n, energy gain on each cell ΔW_n, the relative velocity of ions β_n, length of cells L_n, a synchronous phase φ_S, extent of bunch F_n, a modulation coefficient m_n, aperture radius α_n, defocusing parameter Δ_n, the factor of focusing B_n, total length of structure z_n are spotted. Main parameters of accelerating structure RFQ for PSS-20 depending on the cell number are given on Fig. 1.

Calculations of beam dynamics on site RFQ are executed. Result of calculations are given in [6 - 8]. It is as a result shown that injected ions with energy 6 keV/nucl. in the course of acceleration to energy 150 keV/nucl. are generated in compact bunch in the extent about $\Phi = 20^\circ$ with transmission of 91% and energy straggling $\Delta W/W = \pm 2\%$.

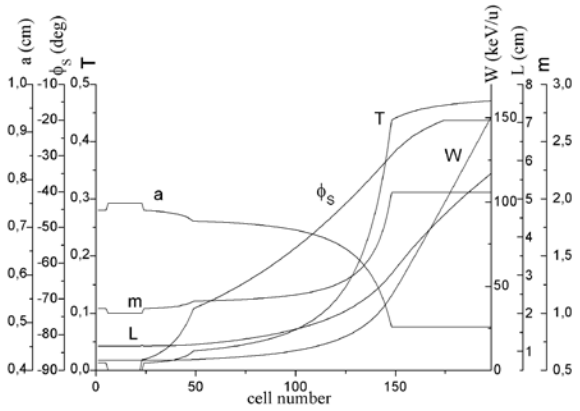

Fig. 1. Main parameters of accelerating structure RFQ for PSS-20

Quantities of the given emittance are in limits 0.4 π mm mrad. The radius of ions beam on exit structure RFQ is in limits ±3 mm (Fig. 2), in Fig. 3 the beam profile at exit of RFQ are given.

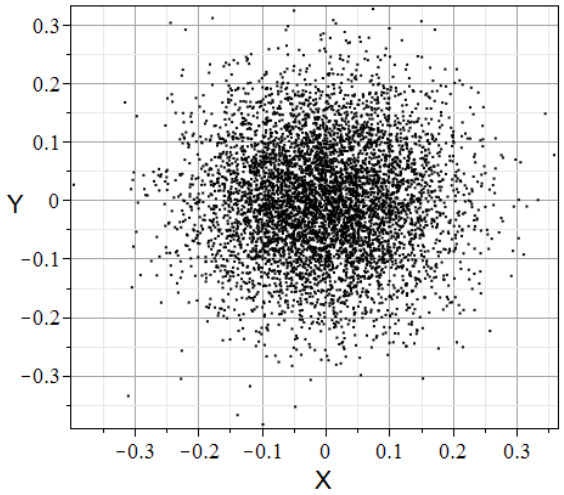

Fig. 2. The radius of ions beam on exit structure RFQ

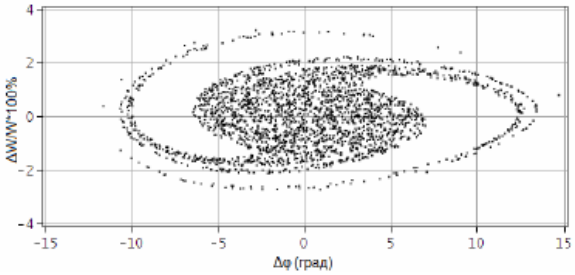

Fig. 3. The beam profile at exit of RFQ

Thus it is shown that accelerating structure RFQ prestripping section PSS-20 has geometrical and electrodynamic characteristics which provide effective process of acceleration of heavy ions of a wide gamut of masses and high current intensity of the accelerated beam.

Presence of site RFQ simplifies a problem of the further acceleration of ions with input energy 150 keV/nucl. in accelerating structure with drift tubes (DTL). At a wave length 6.36 m the length of the first cell of structure DTL makes 5.78 cm. The longitudinal gain of the sizes of cells is carried out already in higher rate, therefore the quantity of drift tubes is reduced. Phase extent of a beam after site RFQ already makes 20°, and radius ±3 mm. It gives the chance to calculate structure of cells with considerably raised quantity of a synchronous phase that increments rate of acceleration and lowers the factor of a defocusing of particles.

In a viewed variant of structure DTL it is supposed to use a combination of alternating phase focusing with restricted quantity of the nets erected on an inlet in aperture holes of some drift tubes [9]. Such variant provides radially-phase stability of a beam in the course of acceleration on length of structure to 4.5 m. This combination will allow to reach the highest rate of acceleration, thus requirements to accuracy of manufacturing and installation of drift tubes considerably decrease.

Various variants of alternation of change of quantity of a synchronous phase and quantity of focalizing nets were studied.

The optimum variant is as a result chosen. Quantity of a synchronous phase on an initial site of structure throughout 15 cells makes φS=0°, and on the others 27 cells remains to a stationary value $\varphi_S = -10^\circ$. For maintenance of radial focusing in such structure focalizing nets are installed in three groups of drift tubes in number of 17 pieces, at total of drift tubes 42 pieces.

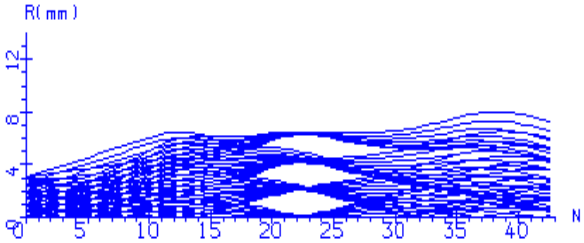

Fig. 4. Radial trajectories of a motion ions for DTL

In Fig. 4 radial trajectories of a motion of ions for which the radius on an input makes 3мм and an angle in limits from +6° to –9° are given. Thus, on an output prestripping section PSS-20 the total intensity current heavy ions beam of taking into account transmission on site RFQ and beam losses on nets structure DTL will make 52% from an injected beam. It will allow at injection of a ions beam nitrogen N^+ intensity 10 mA the accelerated on an output PSS-20 ions beam intensity $1.5 \cdot 10^{13}$p/pulse. That on three orders more than in present prestripping section PSS-15. Then on an output of the main section MS-5 of MILAC accelerator will make a beam with energy the 8.5 MeV/nucl. and intensity of ions $3 \cdot 10^{12}$p/pulse at a pulse length 300 μs.

ACCELERATING STRUCTURE PRESTRIPPING SECTION PSS-20 IN THE COUPLING VARIANT

At coupling of two diverse structures RFQ and DTL in one resonator it is necessary to maintain quantities of electrodynamic parameters on each of sites up to the mark. At the same time, in view of that both structures are excited on a wave with longitudinal magnetic field H_{110}, natural frequency of the coupling resonator changes depending on its length. In this case its quantity becomes less in comparison with frequency on which each of sites separately is attuned. Besides, there is an infringement of the generated distribution of an electric field along each of coupling sites.

To maintain necessary electrodynamic parameters of sites of structures in the coupling resonator, effective

methods of the adjustment are developed, allowing to compensate the specified diversions and to maintain quantity of operational frequency. The developed effective adjusting devices providing both local and global adjustment of distribution of the accelerating field along each of sites are used.

As local adjusting systems devices of adjustment of the inductive character of action, so-called «contrivance», as rods located on the drift tube side, opposite to their holders [10] were used. Contrivances have shown high efficiency at adjustment of each of sites of accelerating structure separately.

As devices of global adjustment on electrodynamic parameters of accelerating structure the ending resonance adjusting device were used [11]. It located on the input and output accelerating structure.

Besides, in the coupling structure there is a necessity of adjustment of level of power of each of sites without infringement of distribution accelerating field. As such devices can be used the volume devices entered into field of the resonator where high quantity of a magnetic field takes place. This field is located on periphery of the resonator which is at an angle 90° in relation to plane of accelerating structure.

Calculation of geometrical and electrodynamic characteristics of the coupling accelerating structure was carried out in a three-dimensional variant. As a result of process of consecutive definition of character of activity of each of adjustment devices geometrical parameters of accelerating structure have been spotted. These investigations have allowed to build up demanded character of distribution of the accelerating field, a necessary relation of levels of amplitude of an accelerating field between sites and to gain operating frequency 47.2 MGz.

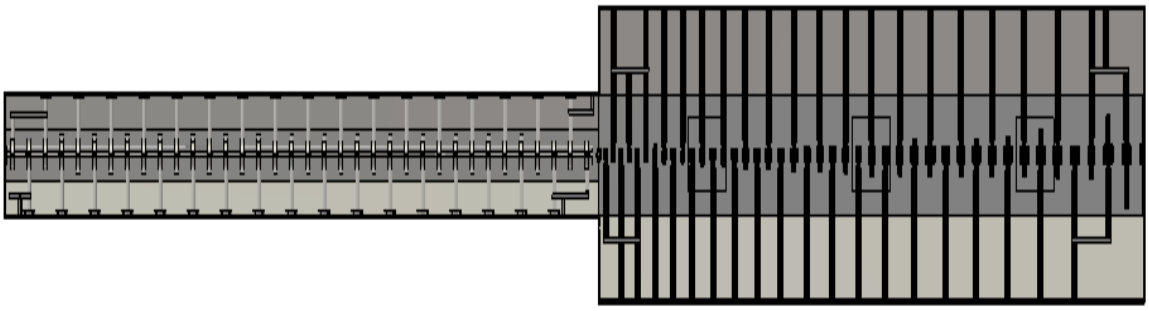

Fig. 5. Accelerating structure prestripping section PSS-20 in the coupling variant structures RFQ and DTL

On Fig. 5 is figured the accelerating structure in which in one resonator sites DTL and RFQ are combined with all devices of adjustment, geometry and which standing has provided demanded quantities of electrodynamic characteristics of accelerating structure prestripping sections PSS-20.

Main parameters of accelerating structure prestripping sections PSS-20 in the coupling variant

Parameters	RFQ	DTL
Input energy, keV/nucl.	6	151
Output energy, keV/nucl.	151	975
Mass to charge ratio, A/q	20	20
Operating frequency, MHz	47.2	47.2
Synchronous phase, deg	87…20	0…10
Cell numbers	198	42
Cavity length,cm	451	423
Tank diameter, cm	50	110
Acceleration rate, MeV/m	0.72	2.9
Output beam emittance π mm mrad	0.456	0.84
Transmission, %	91	66
Pulsed current of accelerated ions, p	$2.88 \cdot 10^{13}$	$1.5 \cdot 10^{13}$

In the table main parameters of accelerating structure prestripping sections PSS-20 in the coupling variant are given.

CONCLUSIONS

Results of process of mathematical modeling of accelerating structure prestripping section PSS-20 of linac MILAC show that the offered coupling of sites RFQ and DTL on interdigital (IH) accelerating structure provides high characteristics accelerated to energy 1 MeV/nucl. of a beam ions of a wide gamut of masses with intensity 10^{13}p/pulse on an input in the main section MS-5. That allows after stripper to accelerate ions with mass to charge ratio $A/q \leq 5$ to energy 8.5 MeV/nucl. and with intensity more 10^{12} p/pulse. New prestripping section PSS-20 will provide a high total level of transmission of ions beam along both coupled sites of accelerating structure. Coupling of accelerating structures RFQ and DTL in one resonator will allow to simplify a construction of accelerating structure prestripping section and will allow to use available equipment and the existing restricted areas. The system of excitation high-frequency power will consist of one generator that considerably will simplify a control system of frequency, a phase and amplitude high-frequency power. All it will provide essential economy of cost of a construction and operation new prestripping section PSS-20 of a heavy ion linear accelerator MILAC.

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СОВМЕЩЕНИЕ УЧАСТКОВ УСКОРЯЮЩИХ СТРУКТУР С RFQ И DTL В ОДНОМ РЕЗОНАТОРЕ ПРЕДОБДИРОЧНОЙ СЕКЦИИ ЛИНЕЙНОГО УСКОРИТЕЛЯ ЛУМЗИ

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Новая предобдирочная секция ПОС-20 состоит из двух участков с разнородными ускоряющими структурами. На начальном участке ускорения ионов от 6 до 150 кэВ/нукл. высокий захват в процесс ускорения обеспечивает встречно-штыревая ускоряющая структура с RFQ. На втором участке ускорения ионов от 150 кэВ/нукл. до 1 МэВ/нукл. высокий темп ускорения создаёт встречно-штыревая ускоряющая структура DTL. Поставлена задача совмещения таких разнородных ускоряющих структур в одном резонаторе.

СУМІЩЕННЯ ДІЛЯНОК ПРИСКОРЮЮЧИХ СТРУКТУР З RFQ ТА DTL В ОДНОМУ РЕЗОНАТОРІ ПЕРЕДОБДИРКОВОЇ СЕКЦІЇ ЛІНІЙНОГО ПРИСКОРЮВАЧА ЛУМЗІ

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Нова передобдиркова секція ПОС-20 складається із двох ділянок з різнорідними прискорюючими структурами. На початковій ділянці прискорення іонів від 6 до 150 кеВ/нукл. високе захоплення в процес прискорення забезпечує зустрічно-штирьова прискорююча структура з RFQ. На другій ділянці прискорення іонів від 150 кеВ/нукл. до 1 МеВ/нукл. високий темп прискорення створює зустрічно-штирьова прискорююча структура DTL. Поставлено завдання суміщення таких різнорідних прискорюючих структур в одному резонаторі.