MODERNISATION OF AN INITIAL PART THE MILAC HEAVY ION LINEAR ACCELERATOR

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Abstract

New pre-stripping section (PSS-20) the MILAC heavy ion linear accelerator with the relation of their mass to charge A/q=20 is developed. That will allow to extend considerably a range accelerating ions and to increase intensity of beams. On an initial part of acceleration of ions from 6 keV/u up to 150 keV/u 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/u up to 1 MeV/u the highest rate of acceleration is created interdigital (IH) accelerating structure with drift tubes. Mathematical modeling geometrical and dynamic characteristics of accelerating structures pre-stripping section PSS-20 is executed. Dynamics of heavy ions in the course of acceleration is optimized.

INTRODUCTION

Main objective of investigations is development a complex on the basis of the Kharkov heavy ion linear accelerator MILAC for modeling of radioactive processes in nuclear reactor core, and also use of the accelerated heavy ions beams for investigations in the field of a nuclear physics and in the applied purposes.

Now MILAC accelerates ions from He^{+} to Ar_{40}^{3+}, i.e. ions of those elements which can be gained in ion source with mass to charge ration of A/q≤15. After the system of injection energy of ions makes 30 keV/nucleon and after acceleration in prestripping section PSS-15 - 0,975 MeV/nucleon. At such energy ions are exposed stripping, i.e. transit through a thin carbon film where their charge is incremented within and, after acceleration in the main section MS-5(DTL with quadrupole focusing) energy of ions makes 8,5 MeV/nucleon. Intensity of the accelerated beam to such energy makes 10^{9}-10^{10} particles/s and essentially decreases for ions with a mass number above 40. Such quantity of a current of the accelerated ions is caused by an out-of-date method of radio-frequency focusing on all extent prestripping section PSS-15.

The procurement problem on new prestripping section PSS-20 of the accelerated heavy ions beams with mass to charge ration of A/q≤20 with energy 1MeV/nucleon and the average beam intensity of 10^{12}-10^{13} particles/s is put.

In a Fig.1 the perspective plan of linac MILAC on which two new sites prestripping section PSS-20 is given, on first of which the accelerating structure with radiofrequency quadrupole focusing RFQ, and on second - accelerating structure with drift tubes DTL is used. On all sections of linac MILAC the interdigital H-type IH accelerating structure is used.

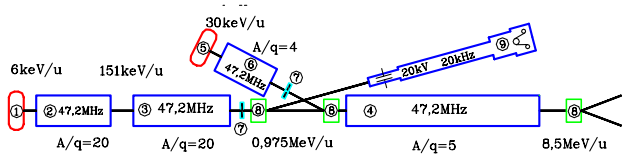

Fig. 1 Perspective plan of linac MILAC.

ACCELERATING STRUCTURE WITH RADIOFREQUENCY QUADRUPOLE FOCUSING RFQ

The accelerating structure with the radiofrequency quadrupole focusing RFQ, the offered I.M.Kapchinsky and V.A.Teplyakov [1,2], is used now almost in all existing heavy ions linacs. The basic design features and methodical workings out have been executed in many accelerating laboratories, studying of such accelerating structure in Los Alamose where all basic backgrounds for structure RFQ construction on sites of formation and an initial acceleration of high-current beams [3,4] have been created was especially intensively conducted. According to these workings out all section RFQ is divided into 4 sites: radial matcher, the phase shaper, a site of the adiabatic grouping (gentle buncher) and an acceleration site (accelerating section). However in case of acceleration of heavy ions (major A/q) the site of the adiabatic grouping demands a considerable quantity of the cells which had on major length. The problem of cutting of total length created prestripping sections PSS-20 together with injection system costs is very sharp. Besides, in a linac of heavy ions intensity of a current of a beam much more low, than in proton accelerators.

Therefore forces of a space charge are small and other plan of grouping providing higher of acceleration rate without deterioration of radially-phase characteristics of a beam can be used. Such plan of acceleration has been offered S.Yamada in which the grouping site is divided into two: prebuncher and buncher. [5]. On a site prebuncher the prompt phase compression proceeding on half of a period of phase oscillations is made. On a site buncher aspire to create high acceleration rate, without worsening thus radial and phase characteristics beam. The site booster where the peak acceleration rate is reached is entered also.

Such variant of build-up of sites prestripping section PSS-20 is developed with reference to acceleration of heavy ions with A/q=20. Thus for each of 6 sites programs of calculation of parameters of structure and characteristics beam of ions are created. Results of optimizing calculations of structure are given in [6]. In Table 1 parameters of accelerating structure and the characteristics beam on an exit of sites of section RFQ for PSS-20 accelerator MILAC are given.

ISBN 978-3-95450-125-0

Table 1: Parameters of accelerating structure RFQ for PSS-20

Parameters	Shaper	Prebuncher	buncher	booster	accelerator
Output energy W, keV/u	6	6,4	44,6	98,3	151
Cell length L, cm	1,138	1,17	3,04	4,55	5,67
Synchronous phase, deg	-87	-72,7	-29,8	-20,2	-20,2
Phase length of bunches F, deg	312,6	236,7	90,2	60,8	60,8
Modulation m	1,04 - 1,00	1,1	2,06	2,06	2,06
Aperture radius a, cm	0,7353 - 0,75	0,71	0,49	0,49	0,49
Efficiency of accelerating T	0,013 - 0	0,034	0,437	0,46	0,47
Section length Z, cm	26,19	29,84	171,04	100,29	123,65
The number of cells	23	26	99	26	24

In a Fig.2 the general view of this structure is presented and on the Fig.3 schematic view of a fragment of accelerating structure RFQ for PSS-20. In a Fig. 4 process of change of parameters along sites of accelerating structure RFQ is figured.

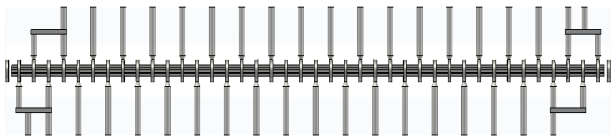

Fig. 2. The General view of structure RFQ for PSS-20

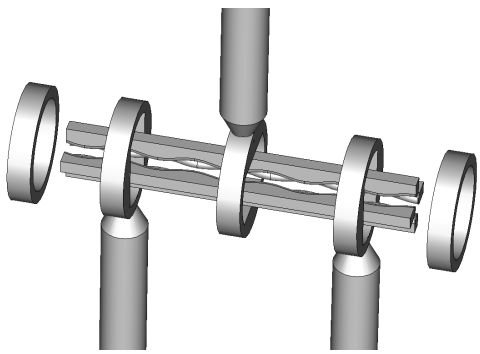

Fig. 3. Schematic view of the fragment of accelerating structure RFQ for PSS-20

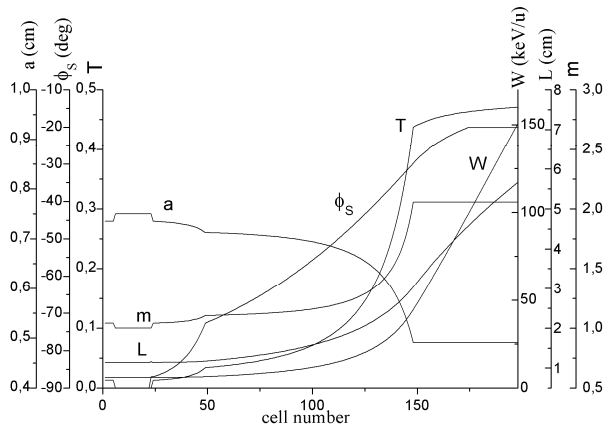

Fig. 4 Mains parameters of accelerating structure RFQ

Energy of ions on an exit from RFQ makes 151 keV/nucleon, the total length of accelerating structure RFQ is equal 451cm, the net quantity of cells - 198. It is necessary to score good characteristics of the accelerated beam of the ions, 95% providing its capture in a following site of acceleration in structure with drift tubes.

SITE OF ACCELERATING STRUCTURE PSS-20 WITH DRIFT TUBES (DTL)

On site PSS-20 with drift tubes the interdigital H-type IH accelerating structure raised on wave H_{110} is used. Prominent feature is such structure is substantial growth of a working wave length that is especially important in case of acceleration of heavy ions with high relation A/q. The economical expenditure of high-frequency power is peculiar to this structure. Besides, acceleration is carried out on π-wave that allows to gain the highest acceleration rate.

Presence of site simplifies a problem of acceleration of the ions which have gained energy 150 keV/nucleon. At a wave length λ=6,36m the length of the first period in structure with drift tubes will make 5,78cm. 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 of ions after RFQ already makes nearby 20°, and its radius 4mm. It gives the chance to calculate structure of cells on considerably raised quantity of a synchronous phase that, accordingly, increments acceleration rate and lowers the factor of a defocusing of particles.

Calculation of accelerating structure with drift tubes is executed. In the course of calculation its geometrical parameters and the basic performances of a beam are spotted. In Table 2 main parameters structure are shown. The total length of structure DTL makes 422,9cm, quantity of cells - 42.

In the course of calculation of dynamics of ions phase and radial characteristics along each group of cells were spotted.

ISBN 978-3-95450-125-0

Table 2: Parameters of accelerating structure DTL for PSS-20

Parameters	Value
Input energy, keV/u	151
Output energy, keV/u	975
Mass to charge ratio, A/q	20
Operating frequency, MHz	47,2
Synchronous phase, deg	-10
Number of drift tubes	42
Cavity length,cm	422,9
Acceleration rate, MeV/m	2,9
Input beam emittance, π mm mrad	0,456
Output beam emittance, π mm mrad	0,84
Longitudinal capture, %	95
Pulsed current of accelerated ions, mA	4,5

Calculations result show that such structure in a combination with site RFQ is effective for making new prestripping section PSS-20 for linac MILAC. Total transmission along all channel PSS-20 is spotted, considering quantity of capture of an injected beam 95%. For example, for ions of nitrogen N^+ at such transmission on an exit prestripping section PSS-20 10^{13} particles/s will be gained. Considering losses on stripper foil by trusty operation of system of autoregulation RF phase, amplitude and frequency a current of ions after acceleration in the main section MS-5 to energy 8,5 MeV/nucleon will make 10^{12} particles/s.

The main objective of mathematical calculations consisted in definition of diameter of the resonator, diameter of drift tubes and a configuration of necessary updatings of the tuning devices which application provides a uniform distribution of an accelerating field along gaps of structure and operational frequency 47,2MHz.

The adjustment problem consists not only in maintenance of necessary operational frequency, but also in neutralisation of decrease of level of a field on ends resonator peculiar to H-structures. Therefore effective methods of adjustment are required, which allow to compensate the specified diversions and to reach operational frequency.

Tasks in view have been solved by the interpolation calculations which consistently joined constructive variants of devices of adjustment: diameter of the resonator, end resonant tuning elements (ERTE), and also the new inductance-capacitor tuning elements – contrivances developed in the course of investigations. Contrivances have shown high efficiency with reference to various variants of accelerating interdigital H-type IH structure - structures RFQ, DTL and others.

Adjusting devices in this case represent a construction in the form of stems which are located on the leg of drift tubes, opposite them support stick to the resonator. They form thus an additional inductance-capacitor loading which yields corresponding to depression of frequencies of cells and local increase of an electric field.

Calculation of geometrical and electrodynamic characteristics of accelerating structure was carried out in three-dimensional variant. As a result of process of consecutive definition of activity of each of tuning elements the method of mathematical modelling had been spotted geometrical parameters of all elements of accelerating structure. These investigations have allowed to gain settlement frequency 47,2MHz and to generate accelerating field.

CONCLUSION

As a result of investigations on development of accelerating structure new pre-stripping section PSS-20 for linac MILAC are created backgrounds for its construction. The design procedure of parameters of two parts interdigital H-type IH structure is developed. These structures based on radio-frequency quadrupole focusing (RFQ) and structure with drift tubes (DTL). These two structures provide both effective formation of heavy ions beam, and high acceleration rate. That will allow on the existing area with restricted length nearby 9м to accelerate heavy ions with the mass to charge ration A/q≤20 to energy 1 MeV/nucleon. Investigations on optimization of parameters pre-stripping section PSS-20 in a direction of combination of diverse sites RFQ and DTL in one resonator will be prolonged. Making such pre-stripping section considerably will raise possibilities of linac MILAC at its use in fundamental scientific investigations and in the applied purposes.

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ISBN 978-3-95450-125-0