https://doi.org/10.46813/2021-134-078

ENGINEERING OF THE LOW-ENERGY BEAM TRANSPORT LINE IN THE He^+ IONS LINAC

S.N. Dubniuk, A.F. Dyachenko, S.S. Tishkin, B.V. Zajtsev
National Science Center "Kharkov Institute of Physics and Technology", Kharkiv, Ukraine
E-mail: sergdubnyuk@gmail.com

The design of a low-energy beam transport line in the helium ions linear accelerator is proposed. For experiments with the low-energy helium ions the vacuum chamber in a transport line is in addition included for an irradiation of investigated materials. The mathematical modeling method investigates coordination variants of an injector beam output emittance with an accelerating structure acceptance with use of electromagnetic quadrupole lenses, electrostatic lenses and the focusing solenoid. It is shown that the optimal variant, ad hoc, is the focusing solenoid application. The calculated value of a current of the helium accelerated ions makes 4.5 mA.

PACS: 29.17.+w

INTRODUCTION

Important problem of development maintenance of safe atomic energetics is the engineering and researches of new constructional materials capable to work in severe constraints of radiating influence. In particular, in an operating time of nuclear and thermonuclear reactors in constructional materials there is a considerable accumulation of helium ions which strongly influence on material properties. In NSC "KhIPT" for imitation of such processes the helium ions linear accelerator (Fig. 1) is used [1 - 4]. On an input in the accelerator particles energy makes 120 keV and on an output is 4 MeV.

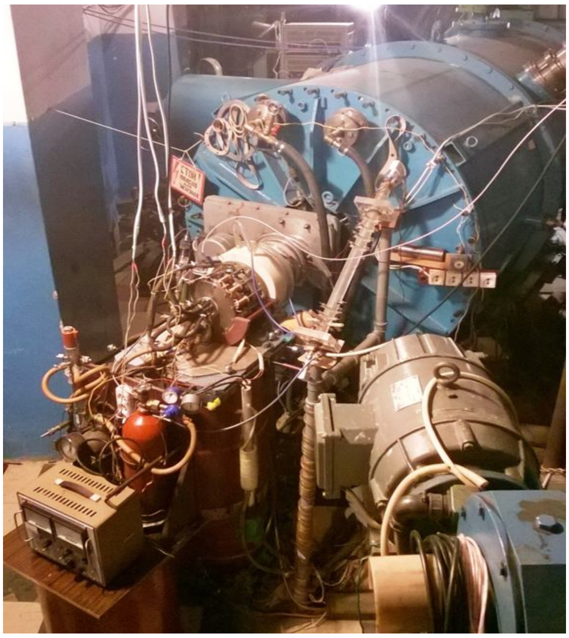

Fig. 1. The He^+ ions linear accelerator (a kind from an injector)

The work purpose is expansion of the accelerator functionality: increase of an irradiation intensity of materials by He^+ ions with 120 keV energy and accelerated ions to energy of 4 MeV on an accelerator output.

For the solution of the posed problem it is offered to use an existing low-energy beam transport line (Fig. 2) in which the chamber for an irradiation of samples (Fig. 3) and a focusing element for the coordination of an injector beam output emittance with an accelerating structure acceptance are added.

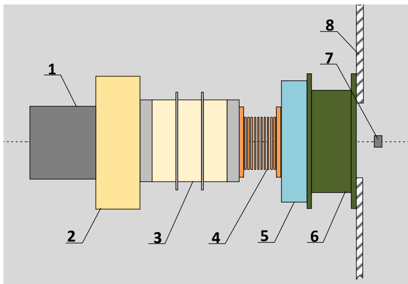

Fig. 2. Existing LEBT, where: 1 – ions source (duoplasmatron); 2 – extraction focusing optics of an injector; 3 – accelerating tube of the helium ions injector; 4 – bellow; 5 – valve (DU-250); 6 – adapter; 7 – flying current sensor; 8 – vacuum housing flange of the helium ions linear accelerator

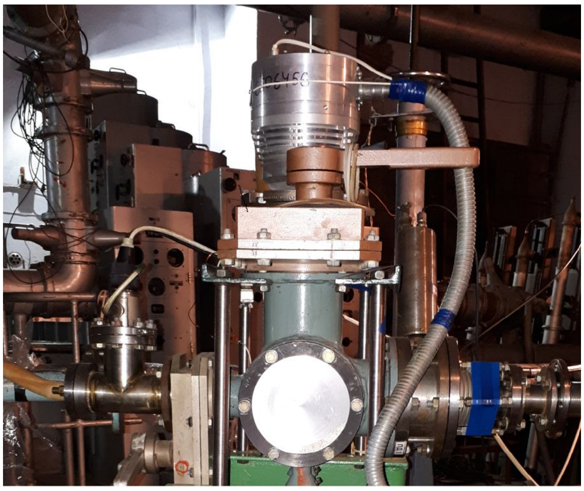

Fig. 3. The chamber for an irradiation of constructional materials

DESIGN OF A LOW-ENERGY BEAM TRANSPORT LINE AND RESEARCH METHOD

Structurally the linear accelerator consists of a helium ions injector with energy of 120 keV, a low-energy beam transport line (LEBT), an accelerating structure with the modified alternating-phase focusing with output energy of 4 MeV [5, 6], a middle energy beam transport (MEBT) line and a chamber for an irradiation of samples. The irradiation of constructional materials with energy of 120 keV is made by helium ions at the switched off high-frequency power in accelerating structure. At the drift through all accelerate-focusing path of the linear accelerator intensity of an injector ionic beam on an input in the irradiation chamber decreases approximately in 8 times.

For increase of an irradiation intensity of samples low-energy helium ions it is necessary to establish in the LEBT an additional irradiation chamber. At absence in the chamber of the sample and the included high-frequency power the accelerator is used in a usual mode with 4 MeV output energy. The calculated value of the accelerated ions current on an output of the linear accelerator taking into account forces of a volume charge, real geometry of the channel and experimentally measured peak values of a high-frequency field makes 6 mA.

The numerical modeling of particles dynamics in the accelerate-focusing channel was spent by means of the program APFRFQ [7] for 30 mA input current and transverse Twiss beam parameters on an input of accelerating structure α = 0, β = 8.9 cm/rad; $\varepsilon_{x,y}$ = 0.01 cm·rad. The existing low-energy beam transport line does not contain the focusing elements providing the coordination of a beam output emittance with an accelerating structure acceptance that leads to decrease of the accelerated ions current.

Experimental value of a current on an output of an accelerating structure of the linear accelerator makes 0.9 mA. Addition of an irradiation chamber in a LEBT will lead to an additional mismatch of a beam between an injector and accelerating structure and, hence, to reduction of a current value of accelerated helium ions. To remove the given problem it is possible, using external focusing elements.

The choice of focusing elements, their number, an arrangement and optimum parameters are defined by a mathematical modeling method. Constructively maximum length on which probably to place focusing elements makes ~ 65 cm, and is not closer, than 32…35 cm before an input in accelerating structure.

The mathematical modeling was spent to two stages. At the first stage the preliminary choice of focusing elements, their relative positioning and parameters at length of ~ 65 cm. A beam current is 30 mA. Twiss beam parameters are α = 0, β = 150 cm/rad; $\varepsilon_{x,y}$ = 0.01 cm rad.

Following focusing elements were used: quadrupole lenses, electrostatic lenses and the solenoid. Criterion of an optimality matching line parameters at this stage is the minimum radius of a beam on an input in accelerating structure.

At the second stage final correction of parameters chosen a LEBT was spent. As criterion of an optimality at the second stage the maximum current of accelerated helium ions on an accelerator output serves.

RESULTS OF THE MODELING

On Fig. 4,a,b,c horizontal (continuous line of dark blue colour) and vertical (dashed line of the red colour) beam envelopes, received on the first stage of researches by the help of programs Trace-3d [8, 9] and APFRFQ are presented. The following variants of a LEBT have been considered.

A LEBT with focusing electromagnetic quadrupole lenses. Scheme LEBT is shown in a Fig. 4,a. Sizes of drift intervals are 1 – 65 mm; 3 – 75 mm; 5 – 70 mm; 7 – 70 mm: 9 – 350 mm; poles of magnetic lenses 2, 4, 6, 8 are 90 mm. Values of magnetic fields gradients in the centre of lenses are 2 – (–3.08) T/m, 4 – (+8.8) T/m, 6 – (–10.5) T/m, 8 – (+6.79) T/m. Diameter of the focused beam is 12 mm.

A LEBT with a focusing five-electrode electrostatic lens. Lens electrodes represent rings with 50 mm internal diameter, 70 mm external diameter, 10 mm thickness. Scheme LEBT is shown in a Fig. 4,b. The sizes of drift intervals are 1 – 350 mm; 3, 5, 7, 9 – 60 mm; 11 – 350 mm; lens electrodes 2, 4, 6, 8, 10 are 10 mm. Potentials on lense electrodes are 2, 6, 10 – 0 kV; 4 – 40 kV; 8 – 44.5 kV. Diameter of the focused beam is 22 mm.

A LEBT with the focusing solenoid. Scheme LEBT is shown in a Fig. 4,c. Sizes of drift intervals are 1 – 290 mm; 3 – 350 mm. Length of the solenoid is 2 – 350 mm. Size of a solenoid magnetic field is 0.75 T. Diameter of the focused beam is 8 mm. In a Fig. 4,d the maximum beam diameter in a LEBT and the focused beam diameter on an input in accelerating structure calculated by the macroparticles method by means of APFRFQ program is shown.

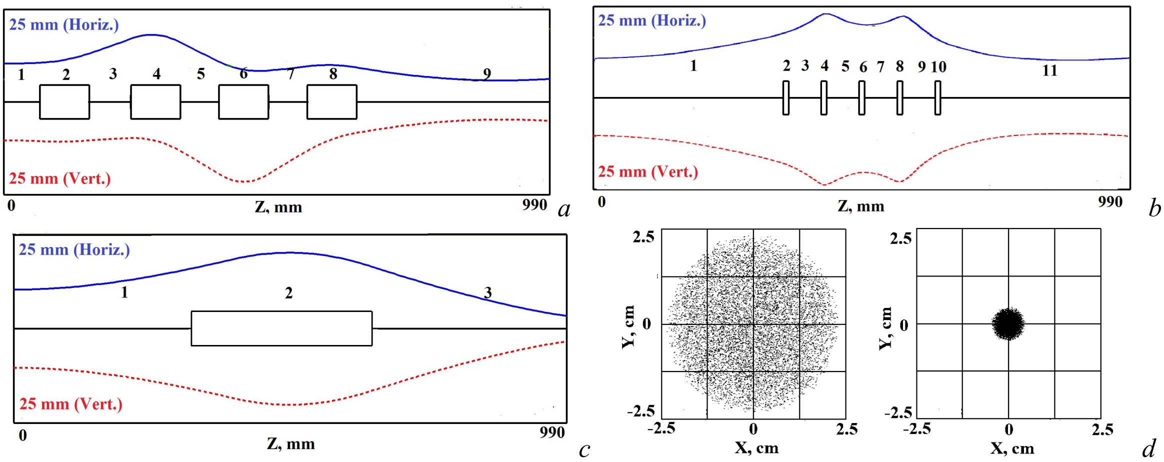

Fig. 4. Schemes of LEBT lines and beam envelopes for various variants: a – focusing by electromagnetic quadrupole lenses; b – focusing by electrostatic lenses; c – focusing by a solenoid; d – the maximum beam diameter in a LEBT with the focusing solenoid (left) and the focused beam diameter on an input in accelerating structure (right)

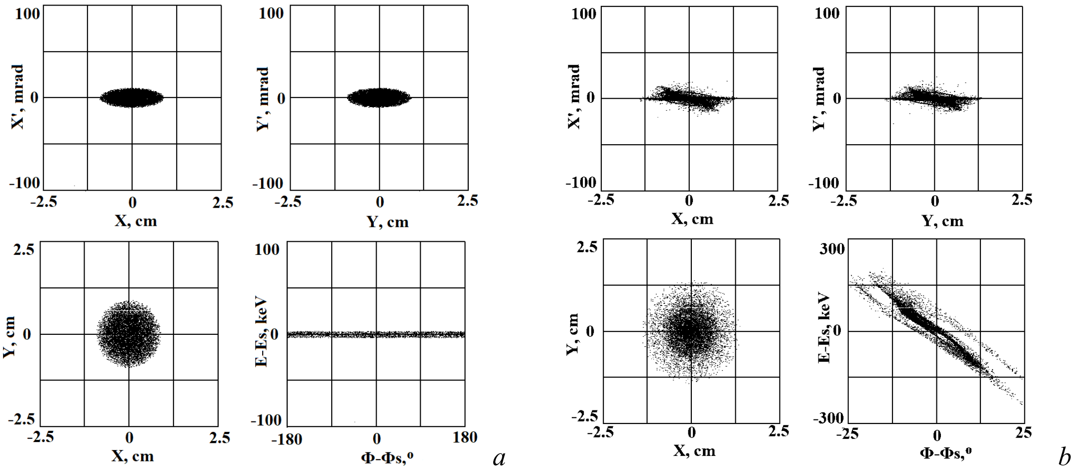

Fig. 5. Parameters of helium ions beam for the channel with output energy of 4 MeV at 30 mA injection current: a – input; b – output

The analysis of these three variants shows that at presence of rather big drift space between focusing elements and accelerating structure the optimal is a LEBT line with the focusing solenoid. The distance between an injector and the solenoid from technological reasons is increased to 400 mm. In a Fig. 5 calculated input and output parameters of beam dynamics which has passed through all accelerator, including a matching line are presented (Fig. 6). Calculation was spent by a macroparticles method under APFRFQ program. Number of injected particles are 100000. Twiss beam parameters on input in a matching line are $\alpha = 0$, $\beta = 84.45$ cm/rad; $\varepsilon_{x,y} = 0.01$ cm·rad. The beam current on an input in the accelerating structure is 30 mA. The beam current on an output of the accelerator is 4.5 mA.

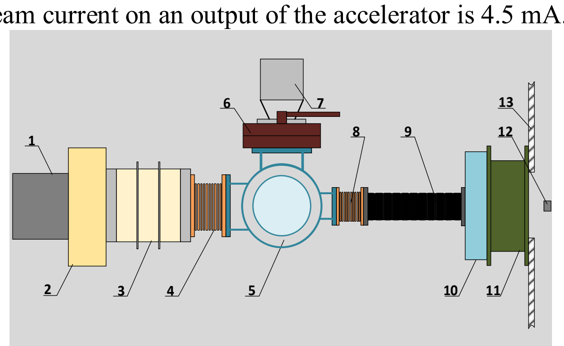

Fig. 6. Final variant of a LEBT, where 1 – ions source; 2 – extraction focusing optics of an injector; 3 – an accelerating tube of the helium ions injector; 4 – bellow; 5 – chamber for an irradiation of samples; 6 – valve (DU-100); 7 – turbomolecular pump; 8 – bellow; 9 – solenoid; 10 – valve; 11 – adapter; 12 – flying current sensor; 13 – vacuum housing flange of the helium ions linear accelerator

CONCLUSIONS

Results of the spent researches testify that the offered transport line of a low-energy beam allows to solve simultaneously two problems. Firstly, to increase an irradiation intensity of constructional materials of helium ions with 120 keV energy in 8 times and, secondly, also to increase an irradiation intensity of helium ions accelerated to energy of 4 MeV in 4 times.

REFERENCES

1. V.O. Bomko, O.F. Dyachenko, O.M. Yegorov, et al. Development of investigations on the MILAC heavy ion linear accelerator // *Proceedings LINAC08*. Vancouver, Victoria, Canada. 2008, p. 187-189.
2. R.A. Anokhin, S.N. Dubniuk, A.F. Dyachenko, et al. Beam and target parameters measurement system on helium ions linear accelerator // *Problems of Atomic Science and Technology. Series “Plasma Electronics and New Methods of Acceleration”*. 2018, № 4, p. 30-35.
3. S.N. Dubniuk, R.A. Anokhin, A.F. Dyachenko, et al. Radiation complex on the basis of helium ions linac // *Problems of Atomic Science and Technology. Series “Plasma Electronics and New Methods of Acceleration”*. 2018, № 4, p. 46-51.
4. A.F. Dyachenko, R.A. Anokhin, S.N. Dubniuk, et al. The bunch formation and transport system to the target of the helium ions linac // *Problems of Atomic Science and Technology. Series “Plasma Electronics and New Methods of Acceleration”*. 2018, № 4, p. 52-55.
5. V.A. Bomko, A.P. Kobets, Z.E. Ptukhina, S.S. Tishkin. Variant alternating phase focusing with step charge of the synchronous phase // *Problems of Atomic Science and Technology. Series “Nuclear Physics Investigations”*. 2004, № 2, p. 153-154.
6. V.O. Bomko, Z.O. Ptukhina, S.S. Tishkin. Variant of the high current linear ion accelerator // *Problems of Atomic Science and Technology. Series “Nuclear Physics Investigations”*. 2006, № 2, p. 163-164.
7. S.S. Tishkin. Combined focusing by RF-field for ion linac accelerators // *Journal of Kharkiv National University. Physical series “Nuclei, Particles, Fields”*. 2008, № 808, Is. 2(38), p. 37-46.
8. W.P. Lysenko, D.P. Rusthoi, K.C.D. Chan, G.H. Gillespie, and B.W. Hill. TRACE 3-D Code Improvements // *Proceedings of the 1996 Computational Accelerator Physics Conference* held September 24-27, 1996 in Williamsburg, Virginia.
9. http://www.laacg.lanl.gov/laacg/services/serv_codes.phtml#trace3d.

Article received 20.05.2021

РАЗРАБОТКА ЛИНИИ ТРАНСПОРТИРОВКИ НИЗКОЭНЕРГЕТИЧЕСКОГО ПУЧКА В ЛИНЕЙНОМ УСКОРИТЕЛЕ ИОНОВ He^+

С.Н. Дубнюк, А.Ф. Дьяченко, С.С. Тишкин, Б.В. Зайцев

Предложена схема линии транспортировки низкоэнергетического пучка в линейном ускорителе ионов гелия. Для экспериментов с низкоэнергетическими ионами гелия в линию транспортировки дополнительно включена вакуумная камера для облучения исследуемых материалов. Методом математического моделирования исследованы варианты согласования выходного эмиттанса пучка инжектора с аксептансом ускоряющей структуры с использованием электромагнитных квадрупольных линз, электростатических линз и фокусирующего соленоида. Показано, что наиболее оптимальным для данного случая является вариант с применением фокусирующего соленоида. Расчетное значение тока ускоренных ионов гелия составляет 4,5 мА.

РОЗРОБКА ЛІНІЇ ТРАНСПОРТУВАННЯ НИЗЬКОЕНЕРГЕТИЧНОГО ПУЧКА В ЛІНІЙНОМУ ПРИСКОРЮВАЧІ ІОНІВ He^+

С.М. Дубнюк, О.Ф. Дьяченко, С.С. Тішкін, Б.В. Зайцев

Запропоновано схему лінії транспортування низькоенергетичного пучка в лінійному прискорювачі іонів гелію. Для експериментів із низькоенергетичними іонами гелію в лінію транспортування додатково включена вакуумна камера для опромінення досліджуваних матеріалів. Методом математичного моделювання досліджено варіанти узгодження вихідного емітанса пучка інжектора з аксептансом прискорювальної структури з використанням електромагнітних квадрупольних лінз, електростатичних лінз і фокусуючого соленоїда. Показано, що найбільш оптимальним для даного випадку є варіант із застосуванням фокусуючого соленоїда. Розрахункове значення струму прискорених іонів гелію становить 4,5 мА.