THE BUNCH FORMATION AND TRANSPORT SYSTEM TO THE TARGET OF THE HELIUM IONS LINAC

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Ways of the bunch current and density increase at the target on the helium ions linear accelerator NSC "KhIPT" with output energy 4 MeV are considered. Possibility of its transportation with the minimum losses to target complex intended for carrying out of radiating researches is studied. Results of the researches spent on electromagnetic quadrupole lenses of a triplet are presented. Experiments with injected (120 кэВ) and accelerated (4 MeV) bunch of helium ions by means of bunch formation and transport system to a target are made.

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INTRODUCTION

Now works are conducted on the new section intended for acceleration of ions He_4^+ (A/q = 4) with injection energy 30 keV/u and output energy 0.975 MeV/u. This section can be used as as an injector in the basic section of BS-5 with output energy 8.5 MeV/u, and it is independent for carrying out of applied researches with output energy of 4 MeV (the helium ions linear accelerator).

Basic elements of the helium ions linear accelerator are: an injector, the resonator with the accelerating structure, placed in a vacuum tank (Fig. 1) and bunch formation and transport system from output of accelerating section to the target chamber with accompanying diagnostic devices for carrying out of physical researches (Fig. 2). A special feature of the accelerator is the use of an alternating-phase focusing (APF) with a step-by-step change in the synchronous phase and an increasing amplitude of the RF field in accelerating gaps on the grouping part of the accelerating-focusing tract [1 - 4].

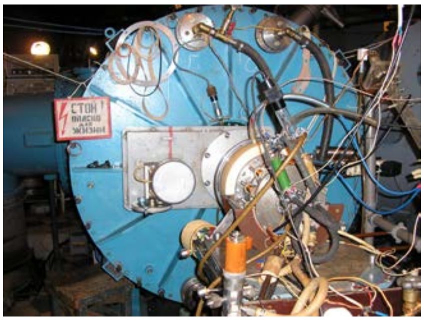

Fig. 1. A source of ions and accelerating structure vacuum tank

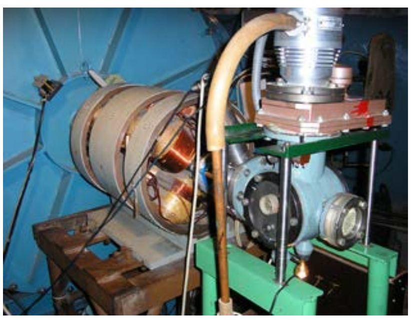

Fig. 2. The bunch formation and transport system from the output of accelerating section to the target chamber

The work purpose is carrying out numerical and experimental researches of various variants of accelerated bunch formation and transport with the minimum losses to target complex intended for realization of radiating researches.

PROBLEM STATEMENT

The new section was created as an alternative variant prestripping section PSS-15 for the further acceleration of particles in the basic section of BS-5 of the linear accelerator. Already at that time there was a problem of the accelerated bunch transport between sections. The similar problem dared earlier after replacement of the basic section with Alvarets structure on new interdigital accelerating structure which almost on 6 m was shorter than the previous. Then not to displace the target devices transporting the accelerated bunch in the chamber for physical researches, the decision to provide new BS-5 with a binding to target devices remaining on former places was accepted. In this connection between sections PSS-15 and BS-5 was formed six-metre-long interval, and there was a necessity of accelerated bunch transport between sections with the minimum losses. The line of the bunch transport, consisting of 3 triplets and a doublet has been for this purpose developed, made and established (Fig. 3) which has successfully worked a number of years.

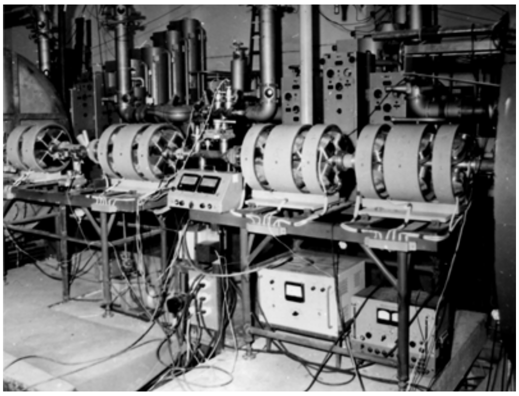

Fig. 3. A line of bunch transportation between sections PSS-15 (on the right) and BS-5 (at the left)

Therefore, when there was a similar problem, we, certainly, have paid attention to available equipment – electromagnetic quadrupole lenses of triplets and doublet with power supplies. Unfortunately, any documentation on these devices has not remained, and specialists too any more were not. That is there were already working triplets and a doublet, but their characteristics were unknown. There was a task of measurement of characteristics available electromagnetic quadrupole lenses, carrying out of their focusing parameter calculations and study of application variants for our problems decision.

Simultaneously the decision of a task not only bunch transport to target complex became essential, but also possibility search substantially to increase its density.

RESEARCH OF CHARACTERISTICS QUADRUPOLE LENSES AND CALCULATION OF THE TRIPLET FOCUSING CHANNEL

For the purpose of carrying out of such measurements near a rack with power supplies electromagnetic quadrupole lenses, long and short lenses with the necessary measuring equipment (Fig. 4) have been placed. The measuring complex contained following elements: the power unit of electromagnetic quadrupole lenses (in drawing it is not shown), a long or short lens, the amperemeter for measurement of the current proceeding in lens M1107 (a class of the device accuracy 0.2), and a magnetic inductometer Ш1-8 (accuracy of the device measurements in a range to 0.4 T – 1.5%).

Fig. 4. A measuring complex for electromagnetic characteristics definition of quadrupole lenses

As for the subsequent calculations it was necessary to define a magnetic field gradient between poles quadrupole lens, measurements of a magnetic induction were spent on different distance from the center of an interpolar circle. For this purpose the special dielectric insert with various depths cuts for installation of a measuring probe on three distances from an interpolar circle center: 4.5, 12.5 and 20.5 mm has been made. For each probe position dependences of a magnetic induction on a current in lenses were measured. The measurement results are given in Figs. 5, 6.

The perform measurements have allowed to calculating magnetic field gradients in lenses for carrying out of the further calculations.

For the decision of bunch transport to a target problem with the minimum losses and increases of its density in our variant the focusing triplet most approaches, with an independent food entering into its composition electromagnetic quadrupole lenses.

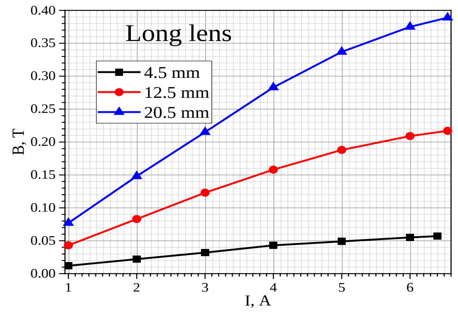

Fig. 5. Dependence of a magnetic induction on a long lens current for probe various positions

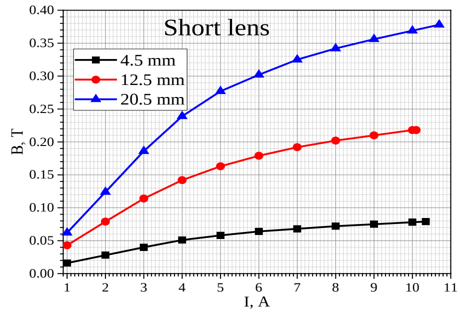

Fig. 6. Dependence of a magnetic induction on a short lens current for probe various positions

Such triplet gives the chance to change operatively density of the bunch current falling on a target, depending on experiment requirements. As the accelerating structure is constructed on the basis of alternating-phase focusing and on output is formed axisymmetric a bunch of ions the most suitable is use of a symmetric triplet for preservation of a transported bunch character. The symmetric triplet consists of three electromagnetic quadrupole lenses with alternating focusing and defocusing properties. The extreme lenses have identical length, and the middle lens length is equal to the sum of extreme lens lengths.

To calculate the transport channel with a focusing triplet and the particles dynamics in it, the output beam characteristics of the structure with APF were obtained using the APFRFQ code: a bunch energy – 4 MeV, a bunch current – 4 мA, a bunch diameter – 30 mm, the beam envelope inclination angle is – 0 мрад [5, 6]. As a result of calculation and optimization of a triplet main parameters: selection of drift interval lengths and magnetic field gradients in lenses values for the transport channel geometry, values of a magnetic field gradients in electromagnetic quadrupole lenses have been received and particles dynamics in such channel is calculated.

In a Fig. 7 are presented: bunch envelope, received for the chosen channel geometry by means of code Trace-3d [7]. Numerals designate drift intervals: 1 – 347.5 mm, 3 – 75 mm, 5 – 70 mm, 7 – 297.5 mm; poles electromagnetic quadrupole lenses: 2 – 90 mm, 4 – 180 mm, 6 – 90 mm. Magnetic field gradients created in the electromagnetic lenses: 2 – 18 T/m, 4 – 15.7 T/m, 6 – 18 T/m. The calculating results received on idealized model, and real values can differ from the experimental a few. By the results of conducting experimental researches and calculations the bunch tracking channel to target complex is generated.

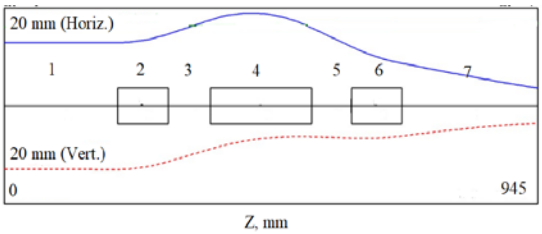

Fig. 7. Calculating results of the transport channel of helium ion bunch from accelerating structure output to the target

RESEARCHES OF THE TRIPLET FOCUSING PROPERTIES ON INJECTED (120 keV) THE BUNCH

At triplet placing on a site of bunch transport to the target chamber the various variants connected with use of measuring devices (cylinder Faraday, induction gauges), by working off connection designs of a vacuum path elements were considered and carried out. Thus the triplet was necessary for placing as it is possible more close to output flange of the accelerator vacuum tank for reduction of the accelerated bunch losses. Necessity of use bellows in transport track for an outcome adjusting elements was the additional negative factor. At the first investigation phase of a triplet focusing properties measurement are spent on injected (not accelerated, energy 30 keV/u) helium ions bunch.

It has appeared that if a bunch current on input in a triplet 1500 μA, and output 700 μA after its inclusion and adjustment (selection of a current values in three lenses for the purpose of the maximum current reception) it is received 1250 μA. Currents were measured by means of the induction gauges established on input and output from a triplet [8].

Further more detailed measurements for studying of a triplet focusing possibilities for the purpose of the maximum current reception on irradiated samples have been spent. For this the scheme of measurements has been changed: induction gauges were established before and after the irradiation chamber. In Figs. 8, 9 the results which show essential influence of currents, proceeding in lenses, on triplet focusing properties are given.

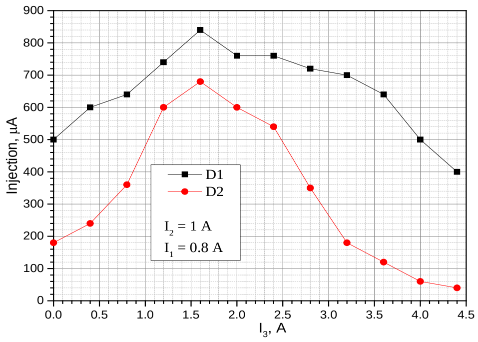

Fig. 8. Dependence of a bunch current on a current in the third lens at I_1 = 0.8 A, I_2 = 1 A. D1 – the induction gauge on irradiation chamber input, D2 – the induction gauge on irradiation chamber output

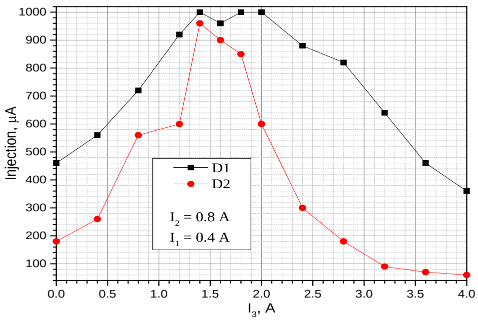

Fig. 9. Dependence of a bunch current on a current in the third lens at I_1 = 0.4 A, I_2 = 0.8 A. D1 – the induction gauge on irradiation chamber input, D2 – the induction gauge on irradiation chamber output

Apparently from Fig. 9 the variant of the maximum current reception on the sample is possible.

RESEARCHES OF THE TRIPLET FOCUSING PROPERTIES ON THE BUNCH ACCELERATED TO 4 MeV

For carrying out of measurements with the accelerated bunch (energy of 0.975 MeV/u) the scheme of measurements has been changed: the induction gauge is established before a triplet. It is necessary that with its help to supervise value of a bunch accelerated current as in a kind of thermostating system absence on the accelerator constant tracing and correcting of bunch parameters is required. The second induction gauge is established after a triplet. Further target chamber settled down on which on a bunch course have established a plate from plexiglas with put on it luminophor for visual indication of the accelerated helium ions bunch. The bunch image on luminophor by means of the webcam was transferred to the computer. At this time measurements of a triplet focusing properties are spent at such research scheme. In Figs. 10, 11 some results of the spent researches are shown.

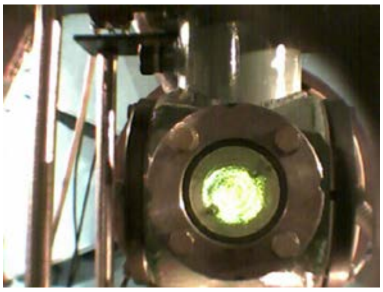

Fig. 10. Accelerated bunch visualization in the absence of a current in triplet quadrupole lenses

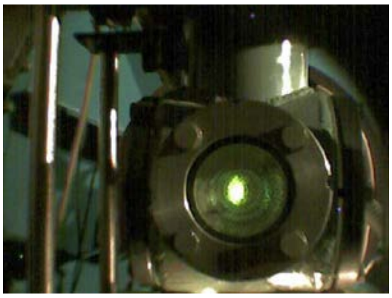

Fig. 11. Accelerated bunch visualization at selection of currents in triplet quadrupole lenses (stain diameter circa 1 cm)

At adjustment of bunch focusing and transport system from an accelerator output to a target the density of its current is essentially increased and close to the necessary value – 1.2×10^{13} particle/s in stain diameter 1 cm.

CONCLUSIONS

The helium ions bunch formation and transport system from an accelerator output to a target are calculated, developed, made necessary elements, assembled and adjusted. The conducted researches of triplet quadrupole lenses, and also parameters injected (energy 120 keB) and accelerated (energy 4 MeV) helium ions bunches have shown that the offered system of helium ions bunch formation and transport on accelerator output allows to increase essentially bunch current density on target and to come nearer to the necessary value – 1.2×10^{13} particle/s in stain diameter 1 cm. This system see can be used as in transport line of the accelerated bunch to the basic section of the accelerator multicharge ions with output energy 8.5 MeV/u, and for increase of current density of helium ions bunch with energy 4 MeV it is direct on a target for carrying out of experimental researches.

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СИСТЕМА ФОРМИРОВАНИЯ И ТРАНСПОРТИРОВКИ ПУЧКА К МИШЕНИ ЛИНЕЙНОГО УСКОРИТЕЛЯ ИОНОВ ГЕЛИЯ

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Рассмотрены способы увеличения на мишени тока и плотности пучка, ускоренного до 4 МэВ на линейном ускорителе ионов гелия ННЦ ХФТИ. Изучена возможность его транспортировки с минимальными потерями к мишенному комплексу, предназначенному для проведения радиационных исследований. Представлены результаты исследований, проведенных на электромагнитных квадрупольных линзах триплета. Проведены эксперименты с инжектируемым (120 кэВ) и ускоренным (4 МэВ) пучками ионов гелия с помощью системы формирования и транспортировки пучка к мишени.

СИСТЕМА ФОРМУВАННЯ ТА ТРАНСПОРТУВАННЯ ПУЧКА ДО МІШЕНІ ЛІНІЙНОГО ПРИСКОРЮВАЧА ІОНІВ ГЕЛІЮ

О.Ф. Дьяченко, Р.А. Анохін, С.М. Дубнюк, А.П. Кобець, А.І. Кравченко, О.В. Мануйленко, В.М. Решетніков, В.А. Сошенко, С.С. Тишкін, Б.В. Зайцев, О.В. Журавльов, В.Г. Журавльов

Розглянуто способи збільшення на мішені струму та щільності пучка, прискореного до 4 МеВ на лінійному прискорювачі іонів гелію ННЦ ХФТІ. Вивчена можливість його транспортування з мінімальними втратами до мішенного комплексу, призначеному для проведення радіаційних досліджень. Подані результати досліджень, що проведені на електромагнітних квадрупольних лінзах триплету. Проведено експерименти з інжектуючим (120 кеВ) і прискореним (4 МеВ) пучками іонів гелію за допомогою системи формування та транспортування пучка до мішені.