ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-MOPSA11

ROOM TEMPERATURE FOLDING SEGMENT FOR A TRANSFER OF MULTIPLE CHARGE STATES URANIUM IONS BETWEEN SECTIONS OF LINAC-100

V. S. Dyubkov, National Research Nuclear University MEPhI, Moscow, Russia

Abstract

Beam dynamics simulations results of multiple charge states uranium ions ($_{238}U^{59+,60+,61+}$) in a transfer line between two LINAC-100 superconducting sections of DERICA project (JINR, Dubna, Russia) are presented. Transfer line is an advanced magnetic optical system and provides beams bending on 180 degrees. Transfer line options are proposed. Parameters of its optic element are chosen so that dispersion function has zero value at the start and end of the channel for transporting the 35.7 MeV/nucleon ion beams.

INTRODUCTION

Fundamental problems such as studies of neutron matter, searching the borderline of nuclear stability in the major part of the nuclear char, studies of nuclei structure far from "stability valley" requires studies of unstable isotopes synthesized in a laboratory. For this reason a construction of radioactive isotope beam "factories" is the mainstream of the low-energy nuclear physics development. One of the mega science facilities for direct radioactive isotopes studies in electron-ion collisions is a rare isotope beam "factory" of FLNR (JINR) called "Dubna Electron-Radioactive Ion Collider fAcility" (DERICA) [1]. DERICA will consist of a number accelerators. The main of them is quasi-CW superconducting driver LINAC-100 [2, 3] that will accelerate heavy ions and will be used for secondary radioactive ion production. Two-step stripper approach is proposed for LINAC-100 [4]. Numerical simulations of uranium beam stripping shows that only 22% of initial beam intensity for one charge state of uranium ions can be obtained. In order to reach world record of beam current on the target it needs to accelerate charge states of uranium ions closed to central one that is considered to be 60. $_{238}U^{59+}$ and $_{238}U^{61+}$ ions appear in stripping the beam. Doing so one can obtain the three charge states uranium ion beam with intensity is about 60% and total beam current of about 0.6 mA under 1.1 π·mm·mrad normalized transverse beam emittance. A similar technique was used in [5].

There are two options of LINAC 100 layout nowadays. One of them the so called "serial" option, when the second LINAC-100 section is placed straight after the first one. Another one is the so called "parallel" option, when the second LINAC-100 section is placed in parallel to the first one. Diagram of the international accelerator-storage complex DERICA in the case of the "parallel" option is shown in Fig. 1. In this case folding segment (marked by I in Fig. 1) for a transfer of multiple charge states uranium ions between sections of LINAC-100 is required. One of the main restrictions for a transfer line is a demand of a zero dispersion function at the end of it. In this paper folding segment for a transfer of three charge states uranium ions between sections of LINAC-100 is presented.

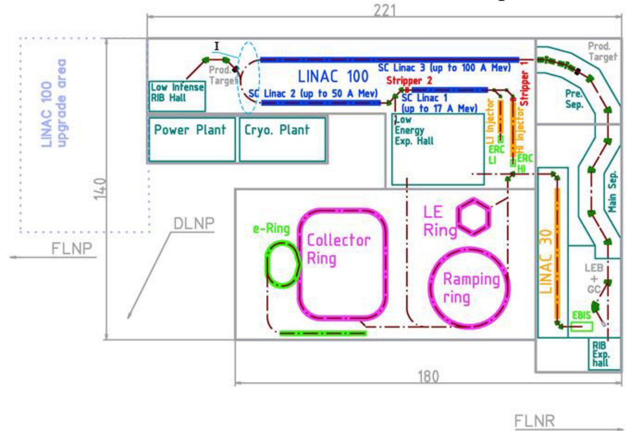

Figure 1: "Parallel" layout option of LINAC-100 for DERICA.

TRANSFER LINE DESIGN

One of a designs for DERICA folding segment was already suggested in [6]. One more option of DERICA folding segment that is called as "current mirror" is presented here. The concept of "current mirror" is widely spread in electron optics. The discussed transfer line layout is presented in Fig. 2.

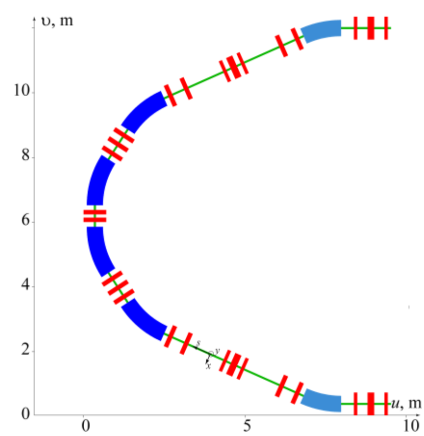

Figure 2: View of the folding segment for heavy ion transfer between sections of LINAC-100.

There are 3 families of quadrupoles and two (33° and 24°) bending magnet families in the transfer line that is a linear achromat. Main magnets parameters are presented in Table 1. Parameters were defined in order to transfer 35.7 MeV/nucleon $_{238}U^{60+}$ ions without transverse size increase and zero dispersion function at the beam exit.

Table 1: Magnet Specifications

Type	Length, cm	Gradient/Feild
Quad type 1	10.0	12.8 T/m
Quad type 1	13.3	0.9 T/m
Quad type 1	13.3	5.3 T/m
Quad type 1	10.0	−1.2 T/m
Quad type 1	10.0	−0.9 T/m
Quad type 2	13.3	0.5 T/m
Quad type 2	13.3	−10.6 T/m
Quad type 2	13.3	−1.2 T/m
Quad type 2	13.3	−0.4 T/m
Quad type 2	13.3	−2.2 T/m
Quad type 2	13.3	−0.8 T/m
Quad type 3	20.0	0.3 T/m
Bend type 1	120.0	1.2 T
Bend type 2	150.0	1.3 T

BEAM TRANSFER SIMULATION

Self-consistent beam dynamics simulations were carried out by means of TraceWin code [7] for hard edge magnets model. Initial ${}_{238}U^{60+}$ beam particles distributions used for transfer simulations are shown in Fig. 3 (initial transverse beam emittances were 0.18π mm·mrad). Horizontal dispersion function for the suggested channel is presented in Fig. 4. Calculated ${}_{238}U^{60+}$ beam particles trajectories and its output distributions are shown in Fig. 5 and Fig. 6 correspondingly. Beam current was 0.2 mA.

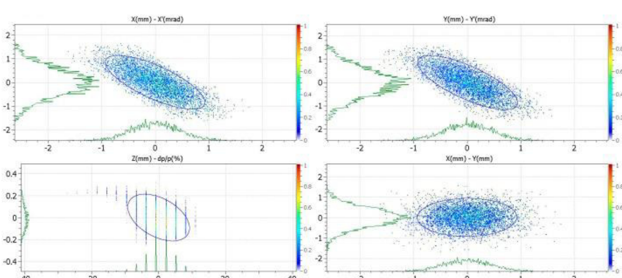

Figure 3: ${}_{238}U^{60+}$ beam particles distributions at the start.

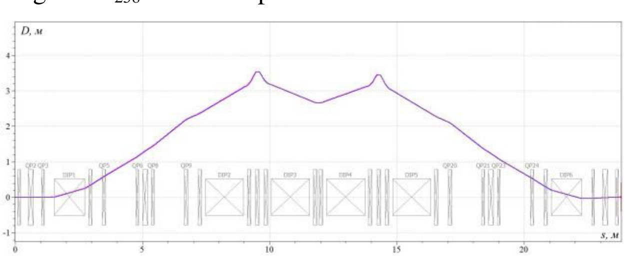

Figure 4: Dispersion function variation along beam path.

After ${}_{238}U^{60+}$ beam transfer simulation it was performed ${}_{238}U^{59+}$ and ${}_{238}U^{61+}$ self-consistent beams transfer simulations. Used initial ${}_{238}U^{59+}$ (35.3 MeV/u, 1.77 mA) and ${}_{238}U^{61+}$ (36.1 MeV/u, 1.83 mA) beam particles distributions are shown in Fig. 7 and Fig. 8.

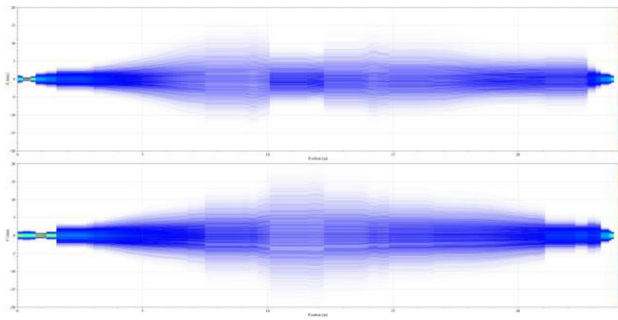

Figure 5: ${}_{238}U^{60+}$ beam density vs its position.

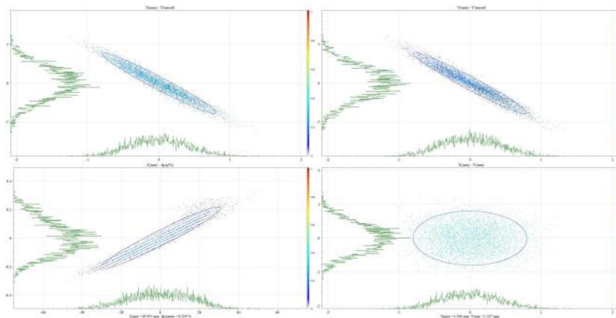

Figure 6: Output particle distribution for ${}_{238}U^{60+}$ beam.

Calculated results of ${}_{238}U^{59+}$ beam transfer throughout "current mirror" are presented in Fig. 9, Fig. 10 and Fig. 11. ${}_{238}U^{61+}$ beam transfer simulation results are shown in Fig. 12, Fig. 13 and Fig. 14. Dispersion function value at the channel end for the ${}_{238}U^{59+}$and ${}_{238}U^{61+}$ beam transfer is equal to 2 cm. Maximal deviations of ${}_{238}U^{59+}$and ${}_{238}U^{61+}$ beam paths from the path of ${}_{238}U^{60+}$ beam are ± 6 cm.

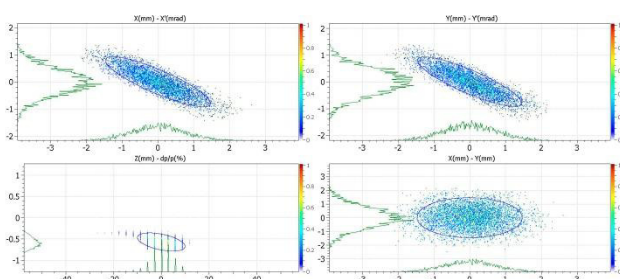

Figure 7: ${}_{238}U^{59+}$ beam particles distributions at the start.

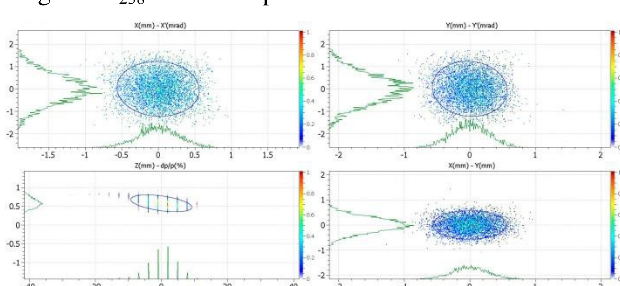

Figure 8: ${}_{238}U^{61+}$ beam particles distributions at the start.

There are no transverse sizes increase at channel exit for all beams under 100% transmission.

ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-MOPSA11

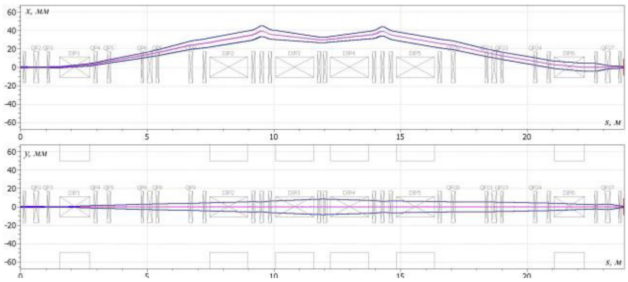

Figure 9: $_{238}U^{59+}$ beam envelopes.

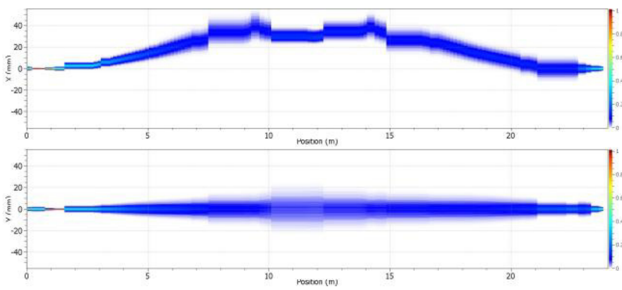

Figure 10: $_{238}U^{59+}$ beam density vs its position.

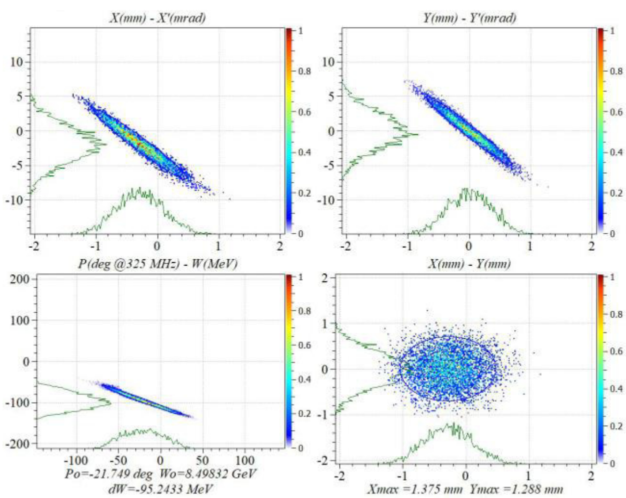

Figure 11: Output $_{238}U^{59+}$ beam particle distribution.

CONCLUSION

Room temperature folding segment for a transfer of three charge states uranium ions between sections of SC LINAC-100 is presented. Suggested transfer line design allow one locate bunchers in the channel in order to manage by beams phase spread. Note, that special care should be taken during magnets design to provide uniform magnetic field of dipoles in the horizontal plane for the region ± 6 cm near central path.

REFERENCES

[1] L.V. Grigorenko *et al.*, "DERICA Project and Strategies of the Development of Low-Energy Nuclear Physics", *Phys. Atom. Nucl.*, vol. 84, no. 1, pp. 68-81, 2021. doi:10.1134/S1063778821010099

[2] L.V. Grigorenko *et al.*, "Design of LINAC-100 and LINAC-30 for new rare isotope facility project DERICA at JINR", in *Proc. HB'18*, Daejeon, Korea, Jun. 2018, pp. 220-225. doi:10.18429/JACoW-HB2018-WEP1WB04

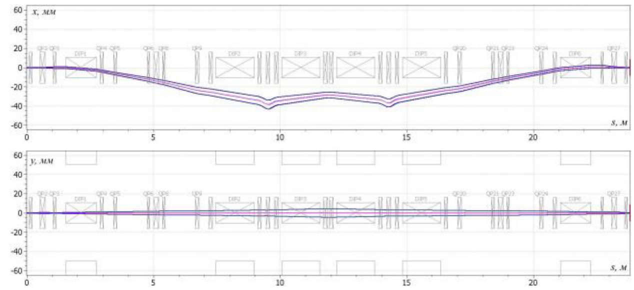

Figure 12: $_{238}U^{61+}$ beam envelopes.

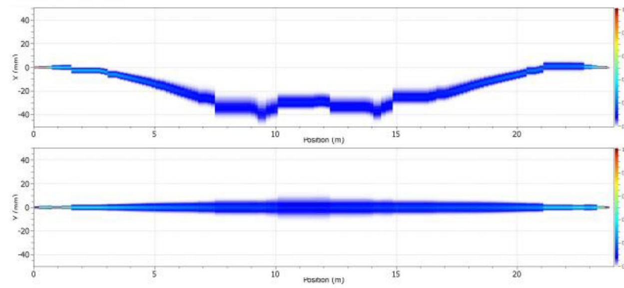

Figure 13: $_{238}U^{61+}$ beam density vs its position.

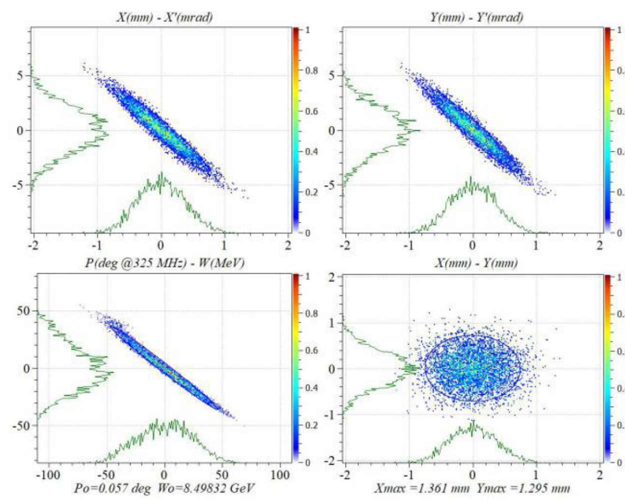

Figure 14: Output $_{238}U^{61+}$ beam particle distribution.

[3] W. Barth *et al.*, "Beam Dynamics Simulation in the LINAC-100 Accelerator Driver for the DERICA Project", *Phys. Atom. Nucl.*, vol. 82, no. 11, pp. 1519-1526, 2020. doi:10.1134/S1063778819110127

[4] W. Barth *et al.*, "Charge stripping at high energy heavy ion Linacs", *J. Phys. Conf. Ser.*, vol. 1350, pp. 012096, 2019. doi:10.1088/1742-6596/1350/1/012096

[5] P.N. Ostroumov *et al.*, "First Simultaneous Acceleration of Multiple Charge States of Heavy Ion Beams in a Large-Scale Superconducting Linear Accelerator", Phys. Rev. Lett., vol. 126, no. 11, pp. 114801, 2021. doi:10.1103/PhysRevLett.126.114801

[6] V.S. Dyubkov and V.Y. Mekhanikova, "Turning channel of uranium ions with suppressed dispersion at the edges for DERICA project", *Phys. Atom. Nucl.*, vol. 83, no. 10, pp. 1471–1477, 2020. doi:0.1134/S1063778820090070

[7] D. Uriot and N. Pichoff, "Status of TraceWin code" // in *Proc. IPAC'15*, Richmond, VA, USA, May 2014, p. 92-94. doi: 10.18429/JACoW-IPAC2015-MOPWA008