12th Int. Particle Acc. Conf. IPAC2021, Campinas, SP, Brazil JACoW Publishing
ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB189

DESIGN AND SIMULATION OF BEAM TRANSPORT LINES OF DC140 CYCLOTRON

V. Lisov †, N. Kazarinov, I. Kalagin, N. Kirilkin, S. Mitrofanov, V. Semin, A. Zabanov
JINR, 141980, Dubna, Russia

Abstract

Flerov Laboratory of Nuclear Reaction of Joint Institute for Nuclear Research carries out the works under creating of FLNR JINR Irradiation Facility based on the cyclotron DC140. The DC140 cyclotron is intended for acceleration of heavy ions with mass-to-charge ratio A/Z within interval from 5 to 8.25 up to two fixed energies 2.124 and 4.8 MeV per unit mass. The intensity of the accelerated ions will be about 1 pmcA for light ions (A<86) and about 0.1 pmcA for heavier ions (A>132). The beam transport system has three lines: for SEE testing of microchip, for production of track membranes and for solving of applied physics problems. The design and simulation of the beam transport system from cyclotron is presented in this report. The beam focusing in the beam lines is provided by set of quadrupole lenses. The beam diagnostics system consists of the Faraday caps, luminophores and the magnetic scanning system.

† lisov@jinr.ru

INTRODUCTION

Flerov Laboratory of Nuclear Reaction of Joint Institute for Nuclear Research continues the works under the creating of Irradiation Facility based on the DC140 cyclotron [1]. Utilization efficiency of the accelerator is determined in many respects by quality of the transportation system for the extracted ions. Widely branched system of the beam lines allows one to carry out numerous investigations.

The irradiation facility will be used for Single Event Effect (SEE) testing of microchips by means of ion beams with energy of 4.8 MeV per unit mass and having mass-to-charge ratio A/Z in the range from 5.0 to 5.5.

Besides the research works on radiation physics, radiation resistance of materials and the production of track membranes will be carrying out by using the ion beams with energy of about 2.124 MeV per unit mass and A/Z ratio in the range from 7.577 to 8.25.

This work is devoted to the further design of the beam lines #1 and #2 for transportation of the extracted heavy ions from the cyclotron to physical targets.

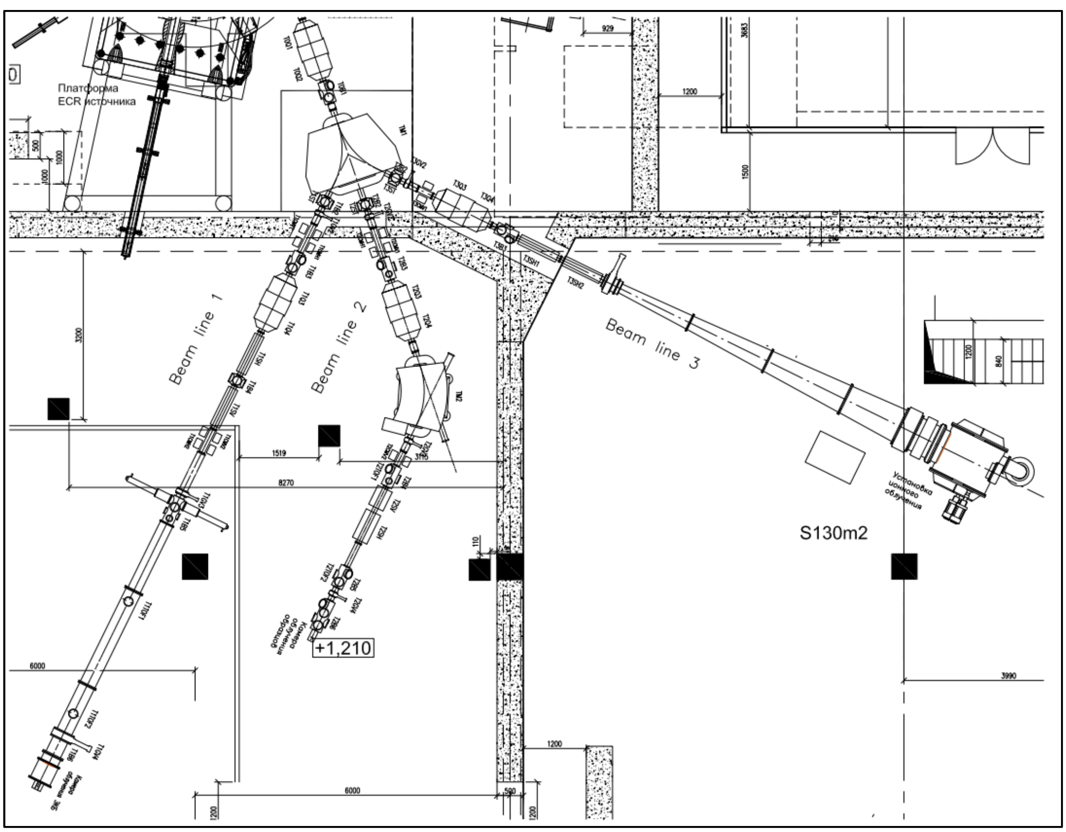

Figure 1: Layout of the beam lines for heavy ion transportation.

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB189

BEAM LINE #1

Layout of the beam line #1 for heavy ion transportation is shown in Fig. 1.

The common part of all beam lines lies from the end of the TCMH magnet (horizontal steering magnet at the extraction point) to the bending magnet (TM1) input (the beam line 0). The beam tracing to the TM1 input is carried out by means of the doublet T0Q1÷T0Q2.

When working with the channel #1, the TM1 is switched on, it turns the ion beam at the angle of 450. There are one doublet consisting of identical standard quadrupoles (besides Q3-Q4, see Fig. 2) behind the bending magnet in the new circuit of this beam line. The total length of this version of the beam line #1 is ~ 16.281 m.

It is supposed that quadrupoles with the following parameters will be used in the beam lines: the effective length l_{eff} = 35 cm ; aperture diameter is D = 11 cm; distance between the quadrupole centres in the doublets Δ = 58 cm; the maximum gradient is Gmax = 6.0 T/m.

The beam line #1 is designed to work with Single Event Effect (SEE) testing of microchips. New scheme of the beam line #1 is shown in Fig. 2.

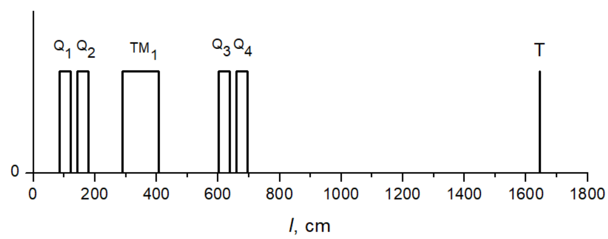

Figure 2: New scheme of the beam line #1. Here Q1-4 are quadrupoles, TM1 is the bending magnet, T is a target.

CALCULATION RESULTS 1

Calculations of the extracted ion beam tracing were carried out with the help of TRANSPORT [2] for the ion beam parameters given in Table 1.

The following designations are used in Table 1. W is the ion beam kinetic energy, $\alpha_x, \beta_x, \alpha_y, \beta_y$ are Twiss parameters, $\varepsilon_{x,y}$ are the RMS values of horizontal and vertical emittances, D_x and D'_x are the values of the horizontal dispersion functions and their derivatives. $\Delta p/p$ is the relative spread of ion momentums.

In the carried out calculations one took into account the influence of the initial ion longitudinal momentum spread $\Delta p/p$. For that, one calculated the behaviour of the dispersion function D_x along the beam trajectory and took into account contribution of the initial ion momentum spread to the behaviour of the horizontal beam dimension.

Quadrupole gradients in the beam lines were chosen so that the beam diameter on the target to be equal to 6.8 cm (4σ) and $D_x = 0$.

As an example of the calculation results, the dependences of the horizontal a_x and vertical a_y ion beam half dimensions (2σ) versus the beam line length for the beam line #1 are shown in Fig. 3 ($^{209}Bi^{38+}$). The dispersion function D_x, D_y is presented in Fig. 4.

Table 1: Initial Parameters of Beams

Ion type (A/Z)	W MeV/u	α_x	β_x cm/rad	α_y	β_y cm/rad	ε_x, $\pi\cdot$cm mrad	ε_y $\pi\cdot$cm mrad	D_x cm	D'_x	$\Delta p/p$ %
$^{40}Ar^{8+}$	4.8	0.69	228.91	-0.74	178.36	0.091	0.16	164.26	-18.61	0.143
$^{209}Bi^{38+}$	4.8	0.3	430.37	-1.04	170.19	0.098	0.147	193.16	9.26	0.135

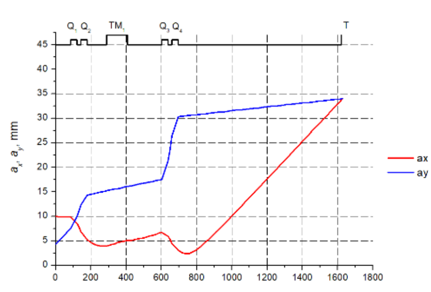

Figure 3 : Horizontal (red curve) and vertical (blue curve) envelopes of the ion beam 209Bi38+.

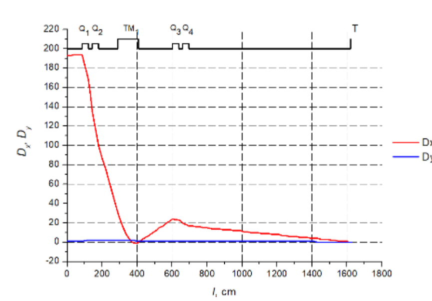

Figure 4: Horizontal dispersion function Dx (red curve) and vertical dispersion function Dy (blue curve) of the ion beam 209Bi38+.

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB189

BEAM LINE #2

The beam line #2 is designed the research works on radiation physics, radiation resistance of materials.

When working with the channel #2, the TM1 is switched off. There are one doublet consisting of identical standard quadrupoles (besides Q3-Q4, see Fig. 5) and bending magnet TM2 behind the bending magnet TM1 in the new circuit of this beam line. The bending magnet TM2 turns the ion beam at the angle of 45^0. The total length of this version of the beam line #2 is ~ 12.803 m. Scheme of the beam line #2 is shown in Fig. 5.

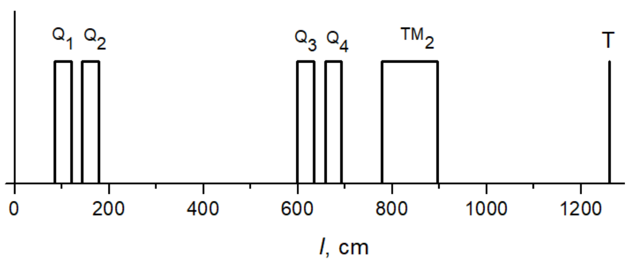

Figure 5: Scheme of the beam line #2. Here Q1-4 are quadrupoles, TM2 is the bending magnet, T is a target.

CALCULATION RESULTS 2

Calculations of transportation of the beam line was carried out for 4 ion beams: $^{40}Ar^{8+}$, $^{209}Bi^{38+}$ (the initial parameters in Table 1) and $^{197}Au^{26+}$, $^{132}Xe^{16+}$ (the initial parameters in Table 2). Quadrupole gradients in the beam lines were chosen so that the beam diameter on the target to be equal to 2 cm (4σ).

The calculation results for ions $^{197}Au^{26+}$, $^{132}Xe^{16+}$, the dependences of the horizontal and vertical ion beam half dimensions versus *l* for the beam line #2 are shown in Figs. 6 and 8. The appropriate dispersion function *Dx* (*l*) is presented in Figs. 7 and 9.

CONCLUSION

The calculations of tracing ion beams of the cyclotron DC140 were carried out for all considered ion beams in both beam lines.

In the beam line 1 the beam diameter of 6.8 cm (4σ) and the value of *Dx* =0 were obtained on the target. In the beam line 2 the beam diameter of 2 cm (4σ) and the value of *Dx* <0.3% were obtained on the target. The required gradients in the quadrupoles have the values not exceeding their limit in all cases considered in both beam lines.

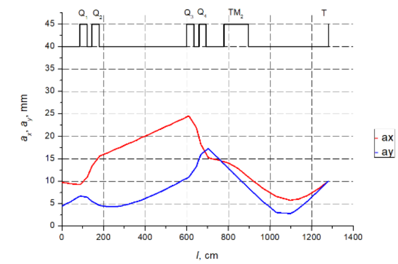

Figure 6: Horizontal (red curve) and vertical (blue curve) envelopes of the ion beam 197Au26+.

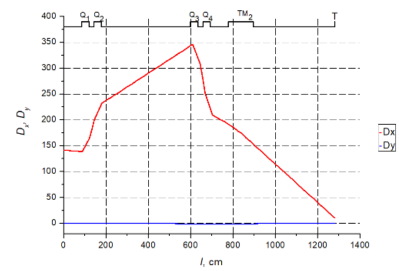

Figure 7: Horizontal dispersion function Dx (red curve) and vertical dispersion function Dy (blue curve) of the ion beam 197Au26+.

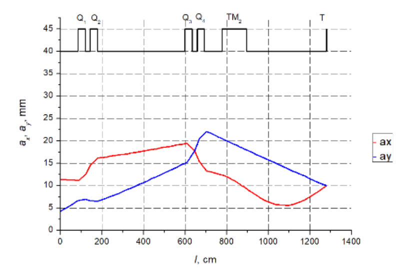

Figure 8: Horizontal (red curve) and vertical (blue curve) envelopes of the ion beam 132Xe16+.

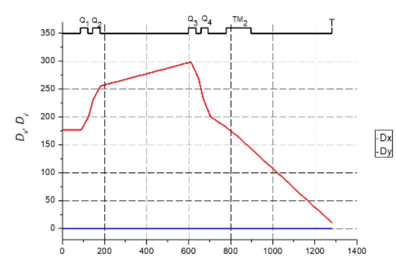

Figure 9: Horizontal dispersion function Dx (red curve) and vertical dispersion function Dy (blue curve) of the ion beam 132Xe16+.

Table 2: Initial Parameters of Beams

Ion type (A/Z)	W MeV/u	α_x	β_x cm/rad	α_y	β_y cm/rad	ε_x, $\pi\cdot$cm mrad	ε_y $\pi\cdot$cm mrad	D_x cm	D'_x	Δp/p %
$^{197}Au^{26+}$	2.124	0.59	240.28	-0.79	177.02	0.1	0.159	141.21	-24.68	0.2
$^{132}Xe^{16+}$	2.124	0.39	420.4	-0.95	170.47	0.093	0.147	177.29	0.48	0.18

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB189

REFERENCES

[1] S. V. Mitrofanov *et al.*, "FLNR JINR Accelerator Complex for Applied Physics Researches: State-of-Art and Future", in *Proc. of 22nd Conf. on Cycl. and their Appl.*, Cape Town, South Africa, Sep. 2019, p. 358-360, doi:10.18429/JACoW-CYCLOTRONS2019-FRB02

[2] PSI Graphic Transport Framework by U. Rohrer based on a CERN-SLAC-FERMILAB version by K. L. Brown *et al.*,

http://aea.web.psi.ch/Urs_Rohrer/MyWeb/trans.htm