BEAM LINES FOR GAS FILLED SEPARATOR EXPERIMENTS AT DC280 CYCLOTRON

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Abstract

The design of two beam lines for ion transportation from the cyclotron DC280 to the Gas Filled Separators (GSF) is presented. The beam lines include commutating magnet with variable magnetic field induction up to 1.5 T that gives the possibility to bend ion beams in five directions providing ion transportation through the beam lines to five experimental setups. The beam focusing in the beam lines is provided by set of quadrupole lenses having the gradients up to 7.7 T/m. The beam lines are intended for the efficient ion transportation of elements from Helium to Uranium with the atomic mass to charge ratio in the range of 4-7.5 at the energies from 4 up to 8 MeV/amu. The ion beam power will reach the value about 3 kW. The water cooled current limiting aperture diaphragms will be installed into all beam lines to prevent the tube damage. The beam diagnostics consists of the Faraday caps (FC), slit collimators, sector aperture diaphragms and ionization beam profile monitors. A new structure of the beam line #3 and calculation results for $^{48}Ca^{9+}$ and $^{48}Ca^{7+}$ ion beam transportation from the extraction point to the new gas-filled separator GFS2 are listed. In addition, a new structure of the beam line #4 and calculation results for $^{48}Ca^{8+}$, $^{50}Ti^{8+}$, and $^{54}Cr^{9+}$ ion beam transportation from the extraction point to the new GFS3 are presented.

INTRODUCTION

DC-280 cyclotron designed at the Flerov Laboratory of Nuclear Reaction (JINR, Dubna) is intended for carrying out fundamental and applied investigations with ions from He to U (masses A from 2 up to 238) produced by a ECR ion source. One may vary the energy of the ions extracted from the cyclotron from 4 up to 8 MeV/amu.

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. Description of the bending magnet and all five beam lines was given in [1].

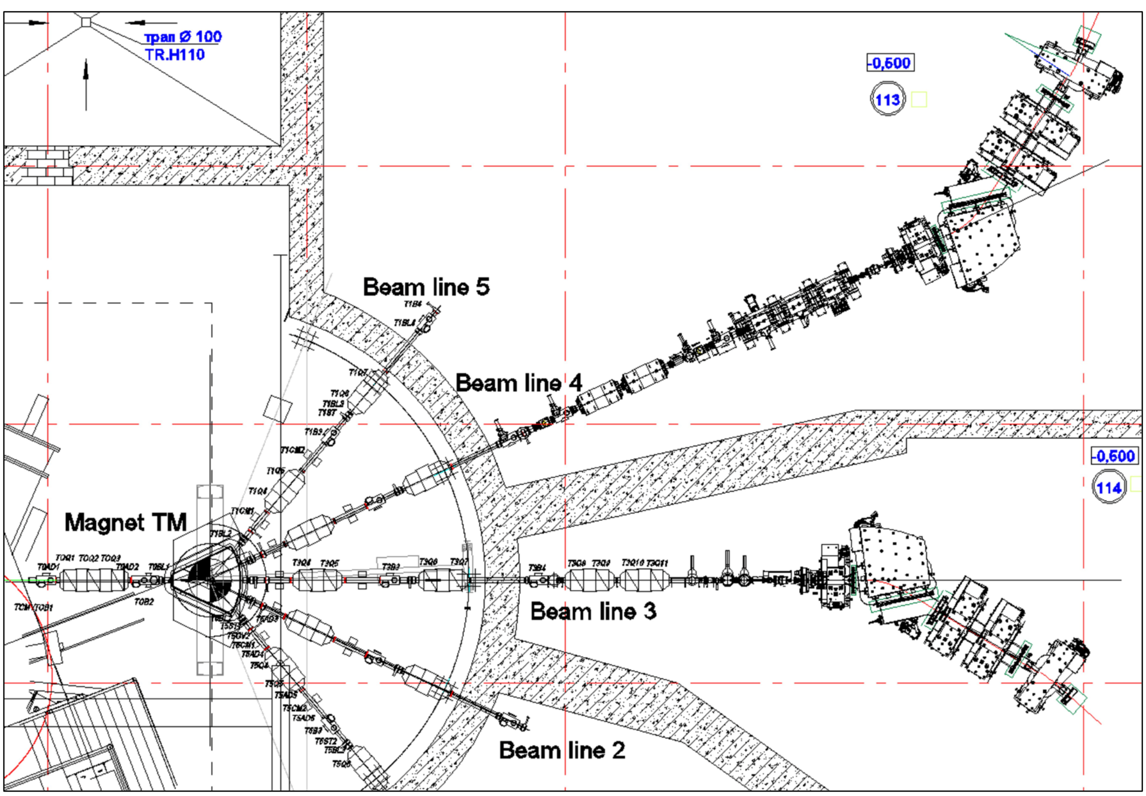

Figure 1: Layout of the beam lines #3 and #4 for heavy ion transportation.

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This work is devoted to the further design of the beam lines #3 and #4 for transportation of the extracted heavy ions from the cyclotron to physical targets.

BEAM LINE #3

Lay-out of the beam line #3 for heavy ion transportation is shown in Fig. 1.

The common part of all beam lines lies from the center of the TCMH magnet (horizontal steering magnet at the extraction point) to the bending magnet (TM) input (the beam line 0). The beam tracing to the TM input is carried out by means of the quadrupole triplet T0Q1÷T0Q3.

When working with the channel #3, the TM is switched off. There are one doublet and a triplet consisting of identical standard quadrupoles (besides Q7, 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 #3 is ~ 14.6 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 G_{max} = 7.7 T/m.

The beam line #3 is designed to work with the new GFS2. New scheme of the beam line #3 is shown in Fig. 2.

The expected ion beam power in the beam lines will be up to 3 kW. Correspondingly, the powerful beams can damage the beam lines. To protect the vacuum tubes against their damage, the water-cooled current limiting aperture diaphragms (32 pieces) will be installed along all beam lines. They will combine function of vacuum seals and water-cooled ring protectors.

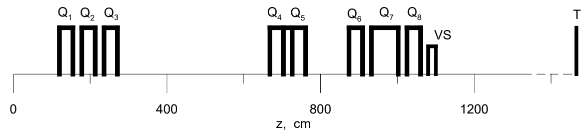

Figure 2: New scheme of the beam line #3. Here Q_{1-8} are quadrupoles, VS is a vertical scanner, T is a target.

The main task in the beam line # 3 was to transport the beam through a system of protective diaphragms for differential pumping between Q_8 and the target so that the beam was as round as possible in this interval. It is necessary to achieve a high vacuum in the beam line with a low vacuum in the GFS2.

Calculation of the beam line was carried out for 2 beams.

CALCULATION RESULTS 1

Calculations of the extracted ion beam tracing were carried out with the help of COSY INFINITY code [2] for the ion beam parameters given in Table 1 [3].

Table 1: Initial Parameters of Beams

Ion type	W MeV/ amu	α_x	β_x cm/rad	α_y	β_y cm/rad	$\varepsilon_{RMS\ x}$ $\pi\cdot$ cm rad	$\varepsilon_{RMS\ y}$ $\pi\cdot$ cm rad	D_x cm	D_x'
^{48}**Ca**$^{9+}$	5.8	-0.956	349.1	0.339	150.15	.2854 10^{-3}	.1256 10^{-3}	386.0	1.285
^{48}**Ca**$^{7+}$	5.8	-3.217	1246.1	-0.418	118.6	.2863 10^{-3}	.1259 10^{-3}	481.7	1.679

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. It was also supposed that relative spread of ion momentums $\Delta p/p$ was equal to $\pm$ 0.2% and the ion beam current was equal to 10 pμA. The values of D_y and D_y' were considered to be equal to zero.

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 10 mm 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 #3 are shown in Fig. 3 ($^{48}Ca^{9+}$). The dispersion function $D_x(z)$ is presented in Fig. 4.

BEAM LINE #4

Layout of the beam line #4 for heavy ion transportation is shown in Fig. 1.

Calculations of transportation of the $^{48}Ca^{8+}$, $^{50}Ti^{8+}$, and $^{54}Cr^{9+}$ ion beams, extracted from the cyclotron DC-280, from the extraction point to the new GFS3 were carried out.

There is the triplet of quadrupoles at the beginning of the beam line #4. Then there is a bending magnet (TM). When working with the beam line #4, it turns the ion beam at the angle of 25^0. Wherein the beam rotates in the direction opposite to its direction in the cyclotron. The input ε_{in} and output ε_{out} pole face rotation angles are equal respectively to 0^0 and +11.5^0. There are also two doublets and a quadruple quadruplet after the bending

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magnet. The total length of the channel #4 is ~ 21 m. New scheme of the beam line #4 is shown in Fig. 5.

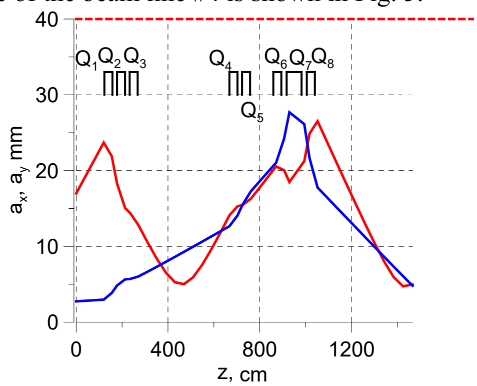

Figure 3: Horizontal (red curve) and vertical (blue curve) envelopes of the ion beam $^{48}Ca^{9+}$.

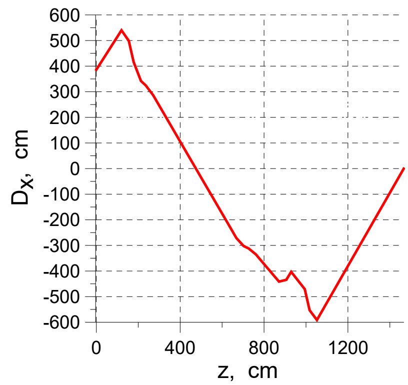

Figure 4: Horizontal dispersion function $D_x(z)$.

CALCULATION RESULTS 2

The beam line #4 was calculated for 4 beams. The initial parameters of these beams are given in Table 2 [4].

As an example of the calculation results, the dependences of the horizontal a_x and vertical a_y ion beam half dimensions versus z for the beam line #4 are shown in Fig. 6 ($^{48}Ca^{8+}$). The appropriate dispersion function $D_x(z)$ is presented in Fig. 7.

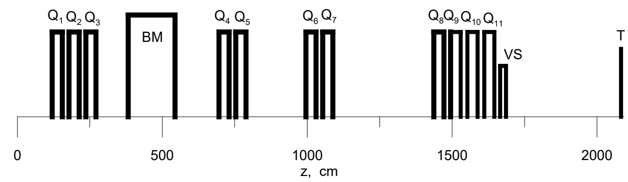

Figure 5: New scheme of the beam line #4. Here Q_1- Q_{11} are the quadrupoles, BM is the bending magnet, VS is a vertical scanner, and T is a target.

CONCLUSION

The calculations of tracing the $^{48}Ca^{9+}$ and $^{48}Ca^{7+}$ beams in the beam line #3 of the cyclotron DC-280 were carried out with the help of the COSY INFINITY code. The beams were traced to the new GFS2.

The calculations of tracing the $^{48}Ca^{8+}$, $^{50}Ti^{8+}$, and $^{54}Cr^{9+}$ beams in the beam line #4 were also carried out. The beams were traced to the new GFS3.

In all cases the beam diameter of 10 mm (4σ) and the value of D_x <10 cm were obtained on the target,

The required gradients in the quadrupoles have the values not exceeding 84% of 770 Gs/cm in all cases considered in both beam lines.

The horizontal and vertical beam half-sizes do not exceed 40 mm, which is determined by the radius of the protective diaphragms, for all considered ion beams in both beam lines.

Table 2: Initial Parameters of Beams

Ion type	W MeV/amu	α_x	β_x cm/rad	α_y	β_y cm/rad	$\varepsilon_{RMS\,x}$ $\pi \cdot$ cm rad	$\varepsilon_{RMS\,y}$ $\pi \cdot$ cm rad	D_x cm	D_x'
^{48}**Ca**$^{8+}$	5.5	-1.726	333.9	0.782	226.7	.2861 10^{-3}	.1259 10^{-3}	328.2	1.053
^{48}**Ca**$^{8+}$	5.3	-2.335	414.4	0.813	315.3	.2848 10^{-3}	.1262 10^{-3}	305.0	0.954
^{50}**Ti**$^{8+}$	5.6	-.943	309.2	0.401	164.2	.2843 10^{-3}	.1255 10^{-3}	373.2	1.233
^{54}**Cr**$^{9+}$	5.74	-1.28	291.4	0.601	216.9	.2831 10^{-3}	.1254 10^{-3}	345.1	1.118

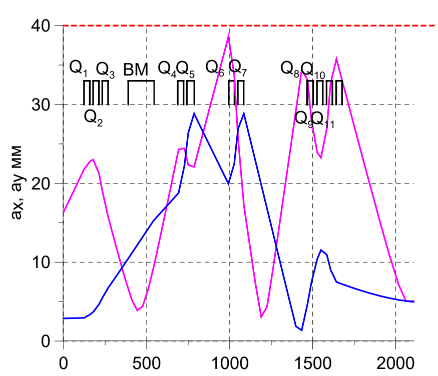

Figure 6: Horizontal (red curve) and vertical (blue curve) envelopes of ion beam $^{50}Ti^{8+}$.

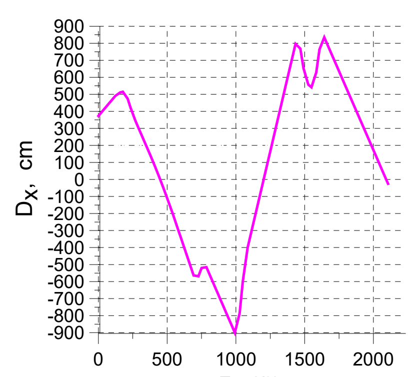

Figure 7: Horizontal dispersion function $D_x(z)$

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