THE PROJECT OF BEAM TRANSPORTATION LINES FOR THE DC-280 CYCLOTRON AT THE FLNR JINR

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Abstract

The project of beam lines for carrying out physical experiments at the DC-280 cyclotron which is being created at the FLNR JINR is presented. The commutating magnet with variable magnetic field induction up to 1.5 T gives us possibility to bend ion beams in five directions providing ion transportation through 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 energies from 4 up to 8 MeV/amu. The ion beam power will reach the value about 3 kW. The water cooled current 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.

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 from A = 2 up to 238) produced by the ECR-source. The energy of the ions extracted from the cyclotron may vary from 4 up to 8 MeV/amu. The main parameters of the DC-280 cyclotron are given in **[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. This work is devoted to the design of the beam lines for transportation of the extracted heavy ions from the cyclotron to physical targets. Lay-out of the beam lines for heavy ion transportation is shown in Fig. 1.

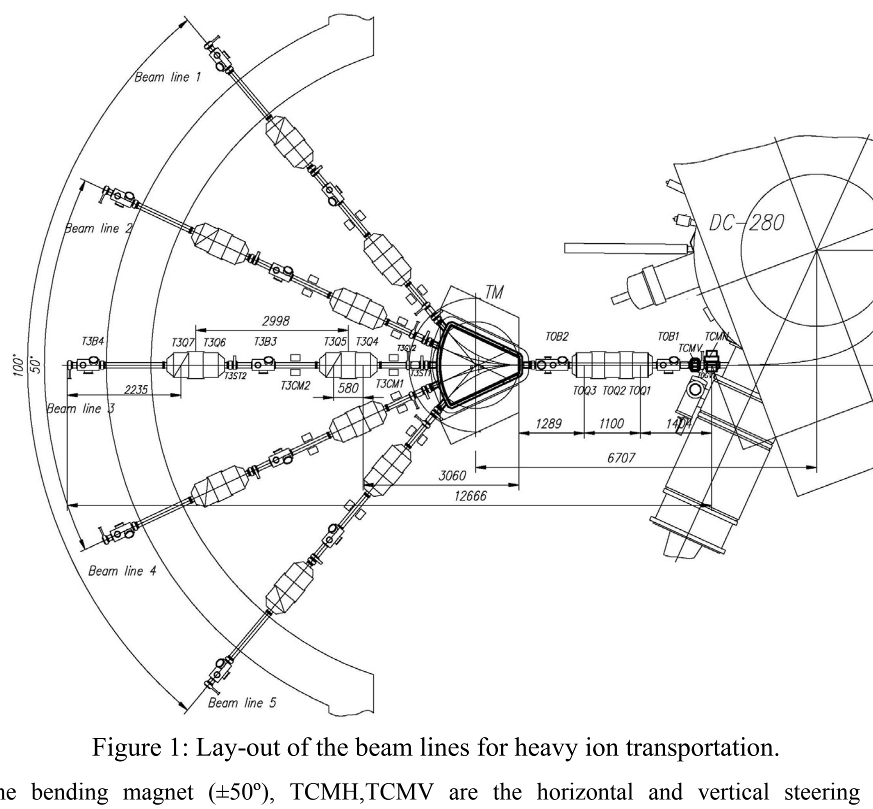

Figure 1: Lay-out of the beam lines for heavy ion transportation.

Where: **TM** is the bending magnet (±50º), TCMH,TCMV are the horizontal and vertical steering magnets at DC-280 extraction,T**x**Q**y** are the magnetic quadrupoles, T**x**CM**y** are the two-plane dipole steering magnets, T**x**B**y** are the diagnostics boxes, T**x**ST**y** are the beam stoppers, T**x**GV**y** are the vacuum gate valves (where: **x** is the beam line number, **y** is the element number).

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DESCRIPTION OF BEAM LINES

The particularity of the beam line system is using one commutating magnet (TM) to bend ion beams to five experimental beam lines, similar to the scheme used at RCNP of Osaka University **[2]**. Every physical setup will be separated from others by concrete walls. After TM the water-cooled beam stoppers will be installed into every beam line to prevent damage of the T**x**GV**2** vacuum gate valve (stopper T**x**ST**1)** and wrong beam transportation to the setups that are prepared to work (stoppers T**x**ST**2**, x=1÷5**)**. The scheme allows beam users to prepare experimental equipment in parallel with beam experiments in the neighbor beam lines, also it is preferable in respect to the cost optimization in comparing with wide spread beam lines.

The common part of all beam lines lies from the center of the TCMH magnet (horizontal steering magnet at the extraction point) to the TM bending magnet input (the beam line 0). The beam tracing to the TM input is carried out by means of the quadrupole triplet T0Q1÷T0Q3. The scheme of the TM bending magnet is shown in Fig. 2 (ABCD outline).

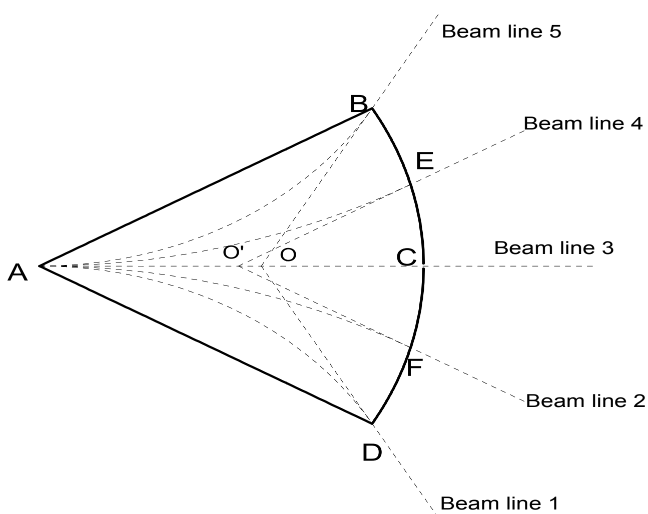

Figure 2. Scheme of TM bending magnet.

The TM has the magnetic field induction up to 1.36 T which bends the ion beam at the angles of $\pm 50^0$ (in the beam lines 1 and 5) and at the angles of $\pm 25^0$ (in the beam lines 2 and 4). When the TM is switched off the ion beam is traced along the beam line 3. Two more quadrupole doublets focusing the ion beam on a target are placed in every beam line behind the TM.

The edge angle at the TM input is ε_{in}=0. The 3D calculations of the TM magnetic field were carried out in [**3**]. The calculation results showed that the edge angles at TM output ε_{out} are equal to $+20.5^0$ for the beam lines 1 and 5, and to $+11.5^0$ for the beam lines 2 and 4. The radius of curvature of the magnetic pole (AC) is equal to 154.1 cm.

It is supposed that quadrupoles with the following parameters will be used in the beam lines: the effective length is l_{eff} = 35 cm ; aperture diameter is D = 11 cm; distance between the quadrupole centers in the doublets is Δ = 58 cm; the maximum gradient is G_{max} = 7.7 T/m.

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 damage, the water cooled current aperture diaphragms (32 pieces) will be installed along all beam lines. They will combine function of vacuum seals and water cooled ring protectors.

CALCULATION RESULTS

Calculations of the extracted ion beam tracing were carried out with the help of COSY INFINITY code **[4]** for the ion beam parameters given in Table 1. They correspond to 3 points on the cyclotron working diagram. The following designations are used in the 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 function and its derivative.

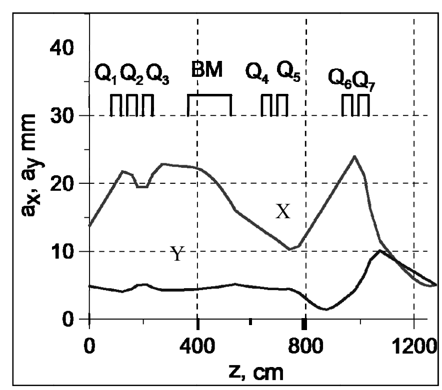

Figure 3. Transportation of $^{48}Ca^{9+}$ ions in beam line 1.

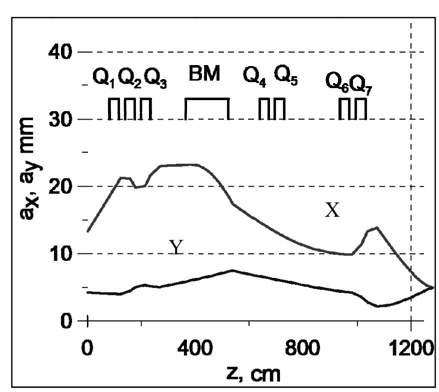

Figure 4. Transportation of $^{238}U^{43+}$ ions in beam line 2.

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Table 1. Parameters of the extracted heavy ion beams.

Ion type	B_0 T	W MeV/u	α_x	β_x cm/rad	α_y	β_y cm/rad	ε_x $\pi\cdot$cm$\cdot$rad	ε_y $\pi\cdot$cm$\cdot$rad	D_x cm	D'_x
$^{40}Ar^{10+}$	0.65	4.0	-17.82	3005.9	-0.018	2214.5	$2.871\ 10^{-4}$	$1.334\ 10^{-4}$	123.8	0.426
$^{48}Ca^{9+}$	1	5.43	-10.4	1738.0	0.222	1600.1	$2.826\ 10^{-4}$	$1.27\ 10^{-4}$	170.8	0.6026
$^{238}U^{42+}$	1.3	7.7	-6.646	1200	-0.121	814.5	$2.852\ 10^{-4}$	$1.284\ 10^{-4}$	196.7	0.6399

It was also supposed that relative spread of ion momentums $\Delta p/p$ was equal to ±0.2% and the ion beam current was equal to 10 pμA. The values of the vertical dispersion function D_y and its derivative 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 $\Delta p/p$ [**5**]. For that one calculated the behavior of the dispersion function D_x along the beam trajectory and took into account contribution of the initial ion momentum spread to the behavior 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 the dispersion function D_x to be close to zero. In the beam lines 4 and 5 the ion beam is deflected in the direction opposite to the beam circulation in the cyclotron.

As an example of the calculation results, the dependences of the horizontal α_x and vertical α_y ion beam half dimensions versus the beam line length z for the beam lines 1, and 2 are shown in Fig. 3 ($^{48}Ca^{9+}$) and Fig. 4 ($^{238}U^{43+}$), where BM is the commutating magnet TM, Q1÷Q7 are the quadrupoles.

BEAM POSITION CORRECTION

The system of beam position correction in the beam lines will consist of the horizontal and vertical steering magnets (TCMH, TCMV) at the cyclotron exit and two two-plane dipole steering magnets (T**x**CM1, T**x**CM2, **x**=1÷5) with length of 50 cm each, located after the TM.

BEAM DIAGNOSTICS

The main part of beam diagnostics will be situated in 12 diagnostics boxes (TxBy, **x**=1÷5, **y**=1÷4). The Faraday caps will be placed in every diagnostics box together with ionization beam profile monitors (IBPM) [**6**] they will be used to measure the ion currents and to determine the ion beam transverse position, the beam profile and intensity distribution in the beam cross section.

The slit collimators will be situated in the T0B2. They will be used to restrict the beam transverse distribution and intensity if it is necessary.

Stationary installed four sector aperture diaphragms will be situated in the beam lines before and after the TM and at the end of every beam line (16 pieces). They will be used for rough estimation of the beam position in the beam lines and for protection of the beam line components from damage due to incorrect beam adjustment.

Two pickup electrodes [**7**] will be placed into the beam line 0. The distance between pickups is equal to 2.4 m. They will be used for measuring the ion beam energy.

The beam intensity will be decreased in 10 times by using the beam chopper system in the DC-280 injection line to measure ion currents by the FC. That allows us to prevent damage and excessive activation of the FC. In routine operation the ion beam current can be controlled by vacuum calibrated IBPM.

VACUUM SYSTEM

The beam line will be pumped by turbo pumps with the pumping speed of 150 l/s installed at the diagnostic boxes and two turbo pumps with the pumping speed of 500 l/s installed at the TM vacuum chamber. The estimated average pressure in the beam lines is about $1\cdot10^{-6}$ Torr, the vacuum beam losses will be not more than 5 %.

CONCLUSION

The project of beam lines for efficient transportation of heavy ion beams extracted from the DC-280 cyclotron to five experimental setups was designed.

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