TRANSPORT CHANNEL OF SECONDARY ION BEAM OF EXPERIMENTAL SETUP FOR SELECTIVE LASER IONIZATION WITH GAS CELL GALS

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Abstract

GALS is the experimental setup intended for production and research of isobaric and isotopically pure heavy neutron-rich nuclei. The beam line consists of two parts. The initial part is used for transport of the primary ^{136}Xe ion beam with the energy of 4.5-9.0 MeV/amu from the FLNR cyclotron U-400M to the Pb target for production of the studying ion beams. These beams have the following design parameters: the charge Z = +1, the mass A = 180-270 and the kinetic energy W = 40 keV. The second part placed after the target consists of the SPIG (QPIG) system, the accelerating gap, the electrostatic Einzel lens, 90-degree spectrometric magnet (calculated value of the mass-resolution is equal to 1400) and the beam line for the transportation of the ions from the magnet focal plane to a particle detector. The results of simulation of the particle dynamics and the basic parameters of all elements of the beam line are presented.

INTRODUCTION

The experimental setup GALS is intended for research of isobaric and isotopically pure heavy neutron-rich nuclei [1].

The beam of ^{136}Xe ions, accelerated in the FLNR cyclotron U400M to the energies of 4.5-9.0 MeV/amu, is transported to the Pb target that is a source of studying secondary ion beams. The primary beam transportation line has the length of 17.9 m from the ion extraction point to the target.

The secondary ion beam has the following design parameters: the charge Z=1, the mass number A=180-270, the kinetic energy W=40 keV and the current up to 1 μA.

The transport channel of the secondary ion beam (see Fig. 1) is located just after the Pb target.
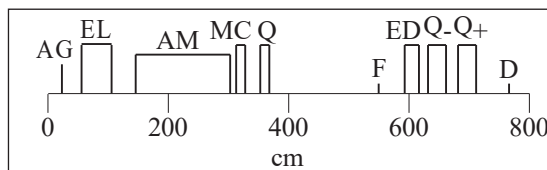

Figure 1: Scheme of the secondary ion beam line.

It consists of the SextuPole Ion Guide (SPIG) system that can be added by QuadruPole Ion Guide (QPIG) system, the accelerating gap (AG), an electrostatic Einzel-

lens (EL), the 90^0 spectrometric magnet (AM), the magnetic corrector (MC), the correcting quadrupole lens (Q), the electrostatic deflector (ED) and the magnetic quadrupole doublet (Q-,Q+).

The results of 3D simulation of the particle dynamics in the spectrometric magnet, calculations of the deflector, and the main parameters of all optical elements of the beam line transporting the secondary ions are given.

PRIMARY ION BEAM LINE

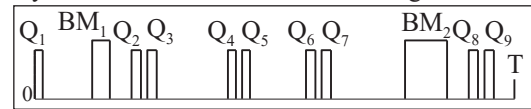Scheme of the beam line for transportation of the primary ^{136}Xe^{47+} ion beams is shown in Fig. 2.

Figure 2: Scheme of the beam line for transportation of ^{136}Xe^{47+} primary beam. BM$_{1,2}$ – bending magnets, Q$_{1-9}$ – quadrupole lenses, T – Pb target.

In calculations, the point of the beam extraction from the cyclotron (point "0" in Fig. 2) coincides with the entrance of the quadrupole Q$_1$.

All quadrupole lenses except of lens Q$_1$ have the effective length l_{eff} =35 cm and maximal gradient Gmax=600 Gs/cm. Quadrupole Q$_1$ has l_{eff} =30 cm and Gmax=190 Gs/cm.

BM$_1$ is 380 sector bending magnet with bending radius of ρ = 1 m. BM$_2$ is 90^0 bending magnet having ρ =1 m and pole face rotation angles $\varepsilon_{in} = \varepsilon_{out}$= 21.5^0.
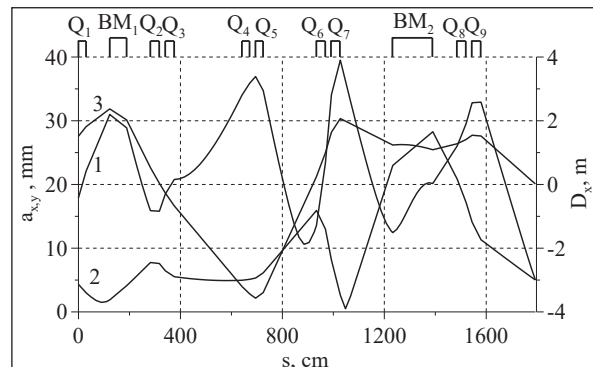

Figure 3: Horizontal a$_x$ (curve 1), vertical a$_y$ (curve 2) envelopes and dispersion function D$_x$ (curve 3) of ^{136}Xe^{47+} beam.

The horizontal and vertical RMS beam emittances are equal to 4.67 and 1.5 π mm mrad respectively. The momentum spread (4σ) of the ions is equal to 2%.

The calculated envelopes (2σ) and horizontal dispersion function of the $^{136}Xe^{47+}$ ion beam with the energy of 9 MeV/amu are given in Fig. 3.

The values of envelopes do not exceed 80% of the beam line aperture. The quadrupole gradients do not exceed their designed maximum values.

SECONDARY BEAM ACCELERATION

Acceleration of the ion beam in the GALS spectrometer is fulfilled in two gaps. The first one with the accelerating voltage of U_0=1 kV is placed at the exit of the SPIG system. The second accelerating gap (AG in Fig.1) with the applied voltage of U=40 kV is placed at the distance Δ=40 mm from the first one.

The object point of the spectrometric magnet AM (the starting point "0" of the beam motion in the calculation) is shifted by distance L from the second gap against the beam movement:

$$L = \Delta\sqrt{\frac{U}{U_0}} = 253 \text{ mm}$$

The initial transverse ion coordinates and velocities correspond to the SPIG system parameters.

SECONDARY BEAM TRANSPORT

The beam diameter at the exit of the SPIG system [1] d_b is equal to 1 mm, the beam emittance for the accelerating voltage U=40 kV is evaluated as 3π mm×mrad.

After acceleration, the ion beam is directed to the analyzing magnet (AM) where the ions are separated in accordance with their masses. The scheme of the beam line for the secondary ion transportation (see Fig. 1) was designed taking into account the results of carried out calculations. The total beam line length is equal to 7.46 m.

Electrostatic Einzel Lens EL

The total length of the electrostatic lens is equal to 50 cm, the maximum value of the voltage at the central electrode V_0= 10 kV. The Einzel lens is designed to correct the position of the AM focus (the point F moves upstream the beam).

Spectrometric Magnet AM

The main parameters of the spectrometric magnet were chosen as follows – rotation angle φ = 90°, ρ = 1 m, maximum magnetic rigidity Bρ = 0.5 T m, the width of the horizontal working region is equal to 100 mm and the gap between the magnet poles is equal to 60 mm. The pole face rotation angles ε_{in} =+50.2^0 and ε_{out} = +6.05^0 were found with the help of the COSY INFINITY code [2].

Correcting Magnet MC

The correcting magnet MC is placed at the exit of the spectrometric magnet AM. The correction is needed to eliminate the influence of the asymmetry of the AM field (see Fig. 4), resulting in a distortion of the equilibrium orbit [3]. It has the main parameters – l_{eff} =15 cm and the maximum magnetic field is equal to 400 Gs.
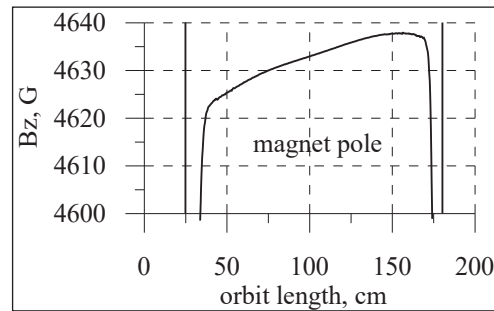

Figure 4: Detailed B_z field distribution.

Magnetic Quadrupole Q

The magnetic quadrupole Q, located at a distance of 50 cm from the AM exit, is designed to adjust the position of the AM focal point F and has the following main parameters: d=80 mm; l_{eff} = 25 cm, G_{max}= 30 Gs/cm.

Electrostatic Deflector

The cylindrical electrostatic deflector ED [4] deflects the separated ion beam with to the particle detector D. The deflector scheme is shown in Fig. 5.
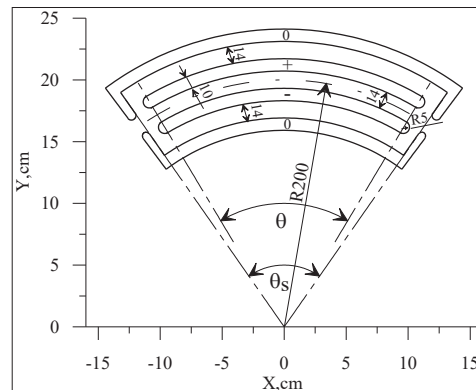

Figure 5: Scheme of the cylindrical GALS deflector.

The deflector consists of two electrodes under potentials U_1 (-), U_2 (+) and two grounded screens (0). Its main parameters are – ρ =20 cm, φ =67^0 and the gap between the electrodes h=14 mm. The optimal value of the angular size of the electrodes θ is equal to 62.6^0. The optimal angular distance between the inner end face of the screens is equal to θ_s = θ+8^0.

The radial thickness of the electrode is equal to 10 mm; the radius of the electrode curvature is equal to 5 mm.

The voltages at the electrodes corresponding to maximum accelerator voltage of GALS setup are equal to U_1 = -2.87 kV and U_2 = 2.78 kV.

Magnetic Quadrupoles Q_-,Q_+

The magnetic quadrupoles Q_-,Q_+ are intended to form an ion beam with the diameter of 5 mm at the particle detector D that is located at the distance of 216.8 cm from the focal plane F of the magnet. The parameters of quadrupoles are – d=40 mm, l_{eff}=30 cm, the gradients G_-= 300 Gs/cm and G_+=500 Gs/cm.

BEAM DYNAMICS IN SPECTROMETRIC MAGNET

3D simulation of the beam dynamics in the GALS spectrometer was carried out in [3]. This simulation used 3D map of the AM magnetic field calculated using OPERA 3D code [5]. The number of particles used in this simulation was equal to 2×10^4. The computational model of the analyzing magnet is shown in Fig. 6. The initial particle distribution in the configuration space is shown in Fig.7. It corresponds to the steady-state exponential distribution of the ion beam with diameter of d_b in the averaged potential of the SPIG system. The distribution is truncated at the boundary value of this potential.
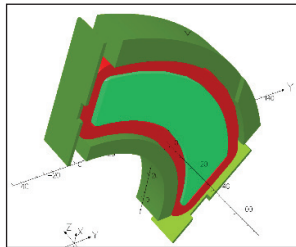

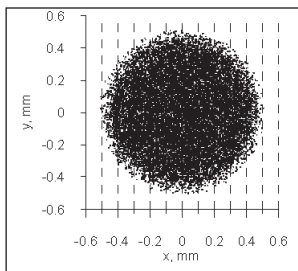
Figure 6: Computational model of the analyzing magnet.

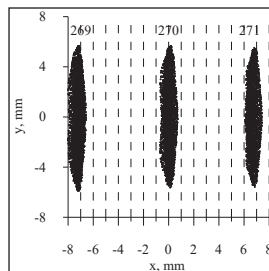Figure 7: Initial particle distribution in plane {x,y}.

Figure 8: Ion distribution in the magnet focal plane.

Figure 8 shows the calculated distribution of the particles in the AM focal plane for the ions with A=269, 270, and 271. The estimated mass resolution of the spectrometer R_m = 1400. The resolution of magnet maybe lower because of fast oscillations of the ions in the RF potential that increases the initial particle angles.

The horizontal and the vertical 100% beam envelopes of the 270^{1+} ion are shown in Fig. 9. The emittance growth due to magnet field nonlinearities is acceptable and does not exceed 25%.
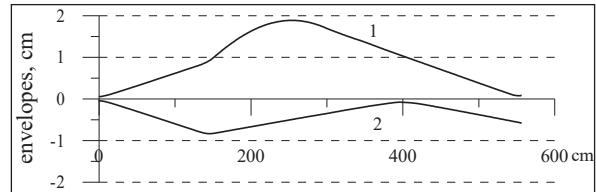

Figure 9: Horizontal (curve 1) and vertical (curve 2) 100% beam envelopes of 270^{1+} ions.

CALCULATION RESULTS OF SECONDARY ION TRANSPORTATION

The dependences of horizontal (curve 1) and vertical (curve 2) ion beam envelopes on distance *s* along the beam line are shown in Fig. 10.
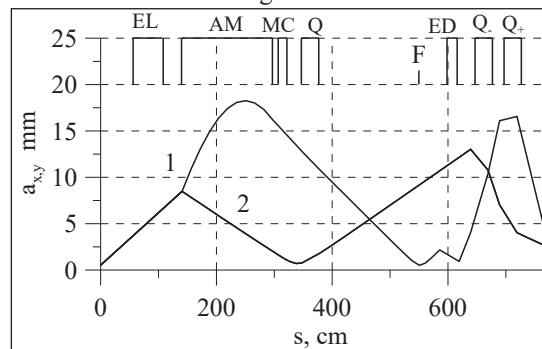

Figure 10: Horizontal (curve 1) and vertical (curve 2) beam envelopes along the beam line.

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