SIMULATION OF HOLLOW BEAM FORMATION AT THE INITIAL PART OF RIB TRANSPORT CHANNEL OF SPIRAL2

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Abstract

The simulation of the hollow beam formation caused by self fields of the multi components ion beam at the initial part of RIB transport channel of SPIRAL2 is fulfilled. This effect increases the RIB emittance and therefore complicates the RIB transport.

INTRODUCTION

The initial part of Radioactive Ion Beam (RIB) transport channel of SPIRAL2 [1] consists of 2.45 GHz ECR Ion Source [2], Einzel lens, focusing solenoid, triplet of quadrupole lenses and 90-degrees analyzing bending magnet. The supporting gas (Nitrogen) current of ECRIS used for the RIB production reaches a value of about 1 mA [3]. The influence of the Nitrogen beam self-fields may lead to a hollow formation in the transported ion beam after the focusing solenoid [4,5]. This effect increases the RIB emittance and therefore complicates the RIB transport. In this paper the numerical simulation of the hollow beam formation is fulfilled by means of MCIB04 code [6]. The threshold current of the ECRIS supporting gas which leads to the hollow formation of the transported ion beam is defined. The influence of the beam neutralization is taking into account. The possible neutralization factor is found from the simulation of the GANIL Test Bench [2]. The simulation of a variant of quadrupoles focusing system of the initial part of RIB transport channel is performed. The influence of the Nitrogen beam space charge on transport of 120u single charged positive ions with energy of 60 keV is studied.

BEAM LINE LAYOUT

The initial part of the RIB beam line is shown in Fig.1.

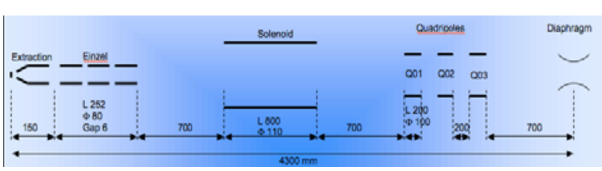

Figure 1: Beam line layout. 90-degrees dipole magnet with orbit radius R of 750 mm is placed at 1500 mm after diaphragm.

ECRIS

ECR ion source with a frequency of 2.45 GHz MONOBOB [2] is most suitable for the production of singly charged ions. The working gas is Nitrogen. The extracted beam kinetic energy is in the range of 10 to 60 keV. The extraction hall diameter is 7 mm. The typical ECRIS magnetic field distribution used in the simulation is shown in Fig.2. The experimentally measured charged state distribution of Nitrogen beam [2] is presented in Fig.3.

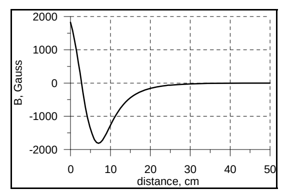

Figure 2:ECR2.45 magnetic field distribution.

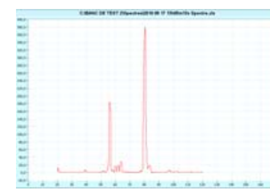

Figure 3: Typical analyzed 770 μA beam, with about 1/3 N+ and 2/3 N_2^+ contribution.

Einzel Lens

On axis potential distribution and longitudinal electric field of lens for 1 kV voltage on central electrode calculated by means of Poisson code is shown in Fig.4.

Solenoid

On axis magnetic field of solenoid calculated by means of Poisson code is shown in Fig.5.

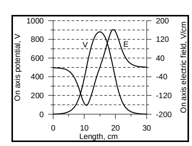

Figure 4: On axis potential (V) and electric field (E).

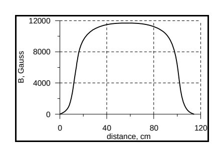

Figure 5: On axis solenoid field distribution.

Quadrupole Lenses

Each lens of triplet has effective length of 200 mm and aperture diameter of 100 mm.

Analyzing Dipole Magnet

The analyzing magnet parameters are contained in Table1. The fringing field is taken into account for magnet calculations in the thin-lens approximation. Pole face curvature is not taken into account.

Table 1: Parameters of Analyzing Magnet

Curvature radius, m	0.75
Bending angle, degree	90
Pole face entrance/exit angle, degree	26.565
Gap height (vertical), mm	90
Maximum magnetic field, T	0.6

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INITIAL BEAM PARAMETERS

An example of standard radioactive beam is $^{40}_{18}Ar$ and other possible beams of interest are He, Ne, Kr and Xe (all single-charged ions). The supporting gas is Nitrogen but Helium is an alternative. The supporting gas current intensity is 0.8 mA (simulation range up to 2 mA). The single charge ion beam (Ar+, 120+) with kinetic energy of 15(60) keV has a waist at the initial point with diameter of 7 mm and full angular spread 17 (22.9) mrad, which is corresponded to 60(80) π mm×mrad beam emittance. Two type of the initial distribution function are used in the simulation – Kapchinsky-Vladimirsky (K-V) and Gaussian truncated at six rms emittance. The full number of macro-particles is equal to 10000. The initial macro-particles distributions for Ar+ ion beam in (x,x′) plane and (x,y) plane for Gaussian type distribution function are shown in Fig.6.

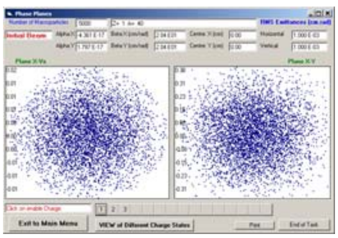

Figure 6: Initial Gaussian distribution. Plane (x,x′) – left, plane (x,y) – right.

HOLLOW BEAM

The explanation of the hole formation in the single-charged ion beam is «short focusing» by the solenoid placed between ion source and analyzing magnet [4,5]. The focusing length of the solenoid for the lighter ions (that is the ion with the smaller mass-to-charge ratio) is less than for single-charged analyzed beam. For this reason in the region between the solenoid and the analyzing magnet the lighter ion beams have the significantly smaller transverse dimensions compared to single-charged beam ones. In the region out of the lighter ion beam boundary the defocusing field decreases as inverse distance of the ions from the axis of the beam. For big magnitude of the lighter ion beam space charge, this leads to formation of the hollow beam of single-charged ions just after analyzing magnet and increases the emittance of analyzed ions beam.

The simulation shows that this effect doesn't depend on type of the initial distribution function and Einzel lens voltage.

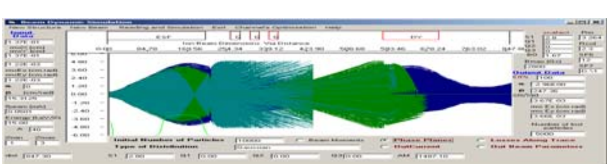

Figure 7 : Particle trajectories.Gaussian distribution.

The particle trajectories in the beam line during Ar+ ions transportation with Nitrogen as supporting gas for Gaussian initial distribution functions are given in Fig.7. The Nitrogen gas current I_N in this case is equal to 0.05 mA, ECR extraction voltage U is 15 kV, and solenoid magnetic field is 2.8 kGs. The Einzel lens voltage is 12 kV. The quadrupole lenses are switched off.

In both cases the single-charged Ar+ ion beam has a hollow form in the focal plane of the magnet. This is illustrated by Ar+ ion (x,y) plane distributions shown in Fig.8.

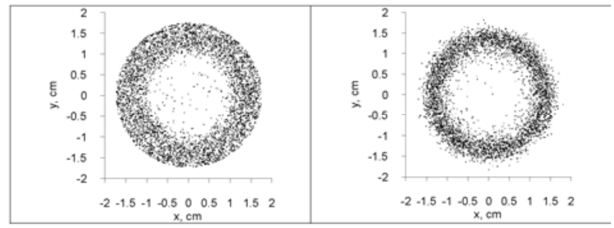

Figure 8a: K-V distr. Figure 8b: Gaussian distr.

THRESHOLD CURRENT

The threshold current I_{th} is minimal current of ECR supporting gas which give the formation of hollow beam of single-charged ion in the focal plane of the magnet. The value of current is depended on extracted voltage as $U^{3/2}$ and charge-to-mass ratio of the supporting gas as $(Z/A)^{1/2}$ and may be approximated by formula:

$$I_{th} = I_0(\xi/\xi_0)^{3/2} \quad ; \quad \xi = (Z/A)^{1/3} U \qquad , \qquad (1)$$

where I_0=0.05 mA, $\xi_0 \cong 5$ kV. The dependence of the threshold current on parameter ξ is shown in Fig. 9.

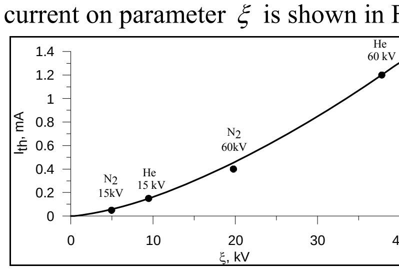

Figure 9: Threshold current. Solid line – formula (1), dots – results of simulation.

BEAM NEUTRALIZATION

The evaluation of a possible neutralization factor of the ion beam is fulfilled by means of Ganil Test Bench (Fig.10) simulation [2].

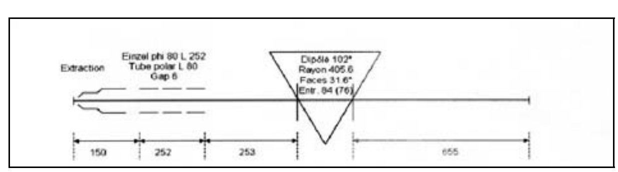

Figure 10: GANIL test bench beam line.

The quantity of neutralization factor also defines the threshold current. In the simulation the value of current of each ion component I_i has been replaced by "neutralized" one I_{in}:

$$I_{in} = (1 - f\,)\,I_i \qquad (2)$$

The value of neutralization factor has been defined to provide approximately 100% transportation efficiency for all ion species of the initial beam. The value found for the neutralization factor is equal to 80%. In all cases the voltage on central electrode of Einzel lens U is equal to 12 kV. Initial distribution function is Gaussian. The results of simulation are shown in Fig. 11.

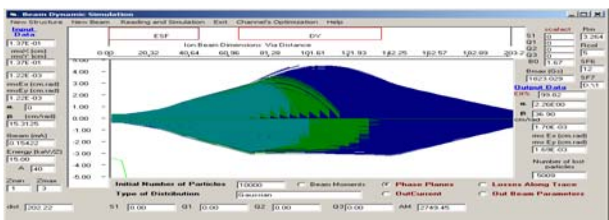

Figure 11: Particle trajectories during Ar+ ion beam analysis. Neutralization factor f = 80%.

The simulation of the ion beam dynamics in GANIL Test Bench gives the estimation of the neutralization factor of ion beam. The value of neutralization factor can not be less than 80%. The threshold current gives the upper limit for neutralization factor ≤94%. Therefore for all values of the neutralization factor within interval 80%≤ f ≤94% the hollow beam formation at initial part of the RIB beam line is possible.

QUADRUPOLES FOCUSING SYSTEM

The simulation of 120+ ions transportation in the presence of quadrupoles focusing system was fulfilled. The 120+ ion beam energy is equal to 60 keV. The Nitrogen beam current is 770 μA. The neutralization factor is 80%. The results of simulation are shown in Fig.12-14.

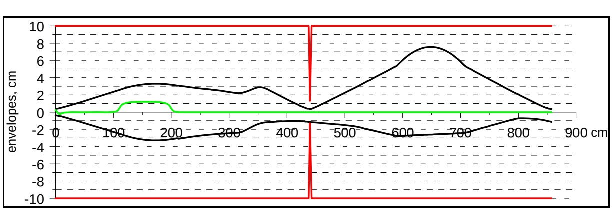

Figure 12: 120+ ion beam envelopes(black lines) and beam line apertures(red lines).

The beam space charge leads to moderate (~10%) increasing of the solenoid field. The beam rms emittance and horizontal dimension at the focal plane of the magnet increase also. This leads to decreasing of the magnet resolution.

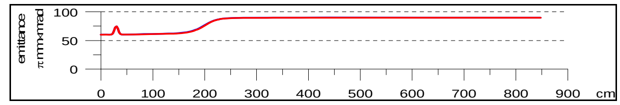

Fig.13:120+ ion beam emittance ($6\varepsilon_{rms}$).

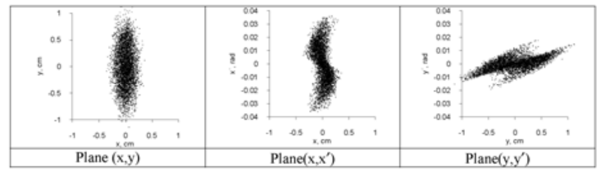

Figure 14: 120+ ion distributions at focal plane of the magnet.

In spite of absence of the hole at the focal plane of the magnet it exists at smaller distance. It is illustrated by Fig.15 where the 120+ ions distribution at 30 cm, 10 cm and 0 cm before the magnet focus are shown.

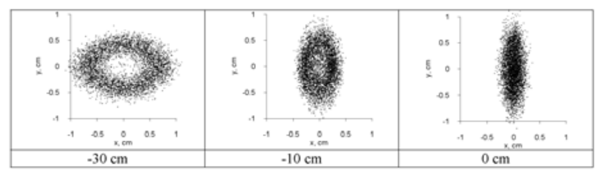

Fig.15: 120+ ions distributions at various distances before magnet focal plane.

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