THE q/m-SEPARATOR FOR REX-ISOLDE

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Abstract

In the planned radioactive beam experiment (REX) at ISOLDE/CERN [1] radioactive singly charged ions are delivered by the online mass separator ISOLDE and are accelerated up to 2.2 MeV/u by a new accelerator concept. The ions coming from ISOLDE are first accumulated, bunched and cooled in a Penning trap (REXTRAP), which is similar to ISOLTRAP [2]. Then, in an electron beam ion source (EBIS) charge multiplication takes place. Finally the highly charged ions are accelerated in a LINAC. As the ions coming out from the EBIS contain impurities coming from residual gas inside the EBIS a q/m selection is necessary before the beam is injected into the LINAC. Calculations show that, a resolving power of 150 is sufficient to ensure that uniquely the radioactive ions pass through the mass slit. In order to reach an energy spread independent resolving power an achromatic system was chosen. In case of higher EBIS emittances a pure magnetic separator system was designed. The third order calculations were done with the COSY INFINITY code [3].

1 INTRODUCTION

The amount of radioactive isotopes from ISOLDE like Na, Mg, K and Ca can be up to 100 times less than the number of residual gas ions coming from REXEBIS like C, N, O and Ar, where Argon is mainly coming from REXTRAP since it uses Ar as buffer gas for ion cooling. An accurate q/m selection must be done before the beam is injected into the LINAC. The REXEBIS axis is 3.1 m above the LINAC axis. The separator consequently should be included in a “S”-shape beam line, which transports the ion beam from the EBIS to the RFQ accelerator. Another task is to ensure an optimal injection into the RFQ accelerator. This paper presents two possible separator systems, where in the first, the ion beam is bent through the “S”-shape by an electrostatic and a magnetic bender, and in the second system both bending elements are magnetic sector fields.

2 REQUIRED RESOLVING POWER

Depending on the vacuum pressure and the EBIS ionization time, the number of residual gas ions coming out from REXEBIS can vary between 10^5 and 10^7. These numbers must be compared with the number of radioactive ions delivered by ISOLDE, which can be for some species even less than 10^4. The comparison of all radioactive ions and residual gas ions with similar q/m was done by using measured masses from [4]. The comparison was done for a q/m range between 0.2 and 0.34, which is specified by the LINAC design. The result was, that with a resolving power of 150 almost all radioactive ions can be separated. An exception is the separation of ^{40}K and ^{40}Ar, where a resolving power of over 20000 is necessary.

3 ENTRANCE CONDITIONS

The EBIS delivers a stigmatic ion beam waste with an expected phase space of $x = 1.5\ mm$ and $x' = 5\ mrad$. These are statistical values with two standard deviations. The energy of the ions coming out from the EBIS, which is the required energy for the RFQ injection is 5 keV/u. For the q/m range specified above, the acceleration voltage (EBIS platform voltage) varies between 14.7 and 25 kV. The energy spread of the beam coming out from the EBIS can reach values similar to the potential depression caused by the electron beam, which amounts to approximately 100 V. For an ion acceleration voltage of 20 kV, one can calculate that the highest expected energy spread should amount to 0.5 %. The overlap between residual gas ions and radioactive ions at the mass slit of the separator must be as small as possible. It is assumed that 10^{-4} of the beam which passes through the mass slit may be residual gas ions. To ensure an overlap not higher than 0.01 %, the phase space distribution of the beam has to be regarded as Gaussian with 4 standard deviations. This means that 99.99 % of the particles are treated in the calculations. The remaining 0.01 % may then pass through the mass slit. A calculation within two standard deviations would treat only 95 % of the beam. The overlap of 5 % would be then too high.

4 TWO POSSIBLE SYSTEMS FOR THE SEPARATOR

For the calculations an energy spread of 0.25 % is assumed (see section 3). In order to obtain a mass resolving power almost independent of the energy spread an achromatic system was chosen. This system consists on an electrostatic and a magnetic bender. The combination of both, as shown in fig. 1 allows the annulment of the energy dispersion at the mass slit. The second order aberrations are corrected by appropriate curvatures of the magnet pole faces. The third order aberrations are diminished by an electrostatic octupole, which is placed at the beginning of the system due to space problems. In case of higher emittances of the EBIS beam a system with 2 magnets was designed (fig. 1, lower figure). The mass dispersion of both magnets adds to a total dispersion of 1.35 mm per mill, which is much higher than the mass dispersion of 0.5 mm per mill of the achromatic system. Furthermore, the electrostatic deflector of the achromatic system allows collimating of the beam

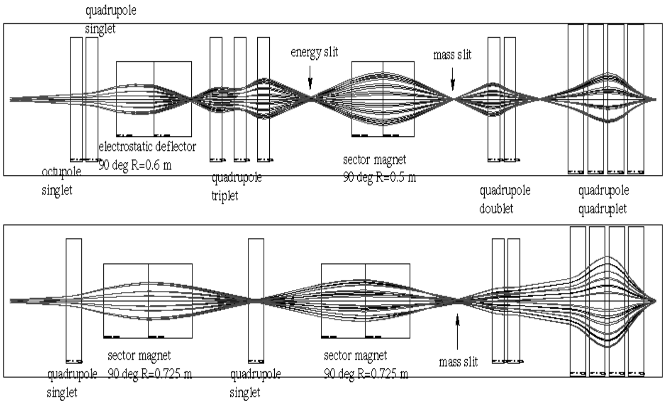

Figure 1: *Straight optical axis representation of the achromatic system (upper figure) and the magnetic system (lower figure) calculated with COSY INFINITY. The calculated trajectories are shown only in the dispersive plane. All quadrupoles are electrostatic. The optical axis has a length of 8528 mm for the achromatic system and 8746 mm for the magnetic system, measured from the EBIS delivering point (left) to the RFQ entrance point (right).*

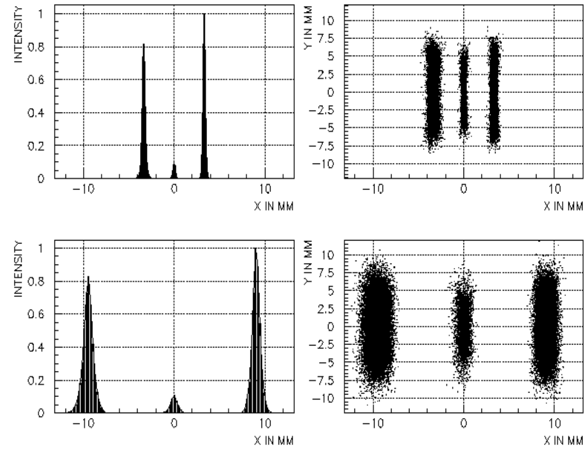

Figure 2: *The ion beam at the mass slit is calculated with the MONTECARLO method. Here 100000 particles are transformed through the COSY INFINITY third order transport matrix. The upper picture shows the conditions at the mass slit of the achromatic system. Analogous the lower picture for the magnetic system. The particles have the mass deviations -1/150, 0 and +1/150. The relative number of particles for the three masses are 10:1:10.*

energy.

5 BEAM PARAMETERS AT THE MASS SLIT

The advantage of using COSY INFINITY is, that the higher order transport matrix can be easily read into a MONTECARLO code. Consequently a large number of particles can be transformed through the transfer matrix. Fig. 2 shows the beam profile at the mass slit for both separator systems. The initial beam phase space was assumed to be elliptic and Gaussian with the 4-σ values $x = 3\,mm$ and $x' = 10\,mrad$. The energy spread was distributed randomly between -0.25 % and 0.25 %.
The resolving power is given as

$$R = \frac{< x|\delta_m >}{2x_f}\ , \tag{1}$$

where the first order mass dispersion matrix element is divided by the final beam diameter. To obtain a more realistic value the resolving power was redefined to be

$$R = \frac{f}{\delta_m} \qquad f = \frac{x_d}{2x_f}\ , \tag{2}$$

where a large number of particles with the mass deviations $-\delta_m$, 0 and $+\delta_m$ are traced through the third order transfer matrix and the total third order mass dispersion x_d and the final spot $2x_f$ are carried out numerically. The final position of each particle is calculated as the sum of all aberrations as proposed in [5]. Using this formalism the resolving power of both systems was calculated for different EBIS emittances. The required resolving power of 150 can be reached for the achromatic system with 4-σ-emittances up to 40 $\pi\ mm\ mrad$. The resolving power is approximately independent of the energy spread. For the magnetic system 4-σ-emittances up to 180 $\pi\ mm\ mrad$ are allowed. For this emittance the energy spread may not exceed 0.1 %.

6 INJECTION INTO THE RFQ

The RFQ accelerator acceptance was calculated to be 200 $\pi\ mm\ mrad$. The injection into the RFQ must ensure a stigmatic focusing and a phase space smaller than the RFQ acceptance ellipse. To obtain a wished phase space in x and y in first order, four quadrupoles are necessary. The four voltages of this quadruplet can than be fitted for the four values x, x', y and y'. As shown in fig. 1 downstream the mass slit and upstream the injection quadruplet, a quadrupole doublet was placed. This has the function to prepare the beam for a magnetic bender, which is placed between doublet and quadruplet and which is not shown in fig. 1. To optimize the RFQ injection in third order this doublet is very helpful. A satisfying injection can be found with different settings of the doublet and the quadruplet. Fig. 3 shows the result of a COSY INFINITY fitting run. As expected, the aberrations in the dispersion plane (in x) are higher than in y. It can be seen that the phase space fits very well into the acceptance ellipse of the RFQ and the beam spot is in good approximation stigmatic.

7 CONCLUSION

The REX-ISOLDE q/m separator has to fulfill two functions, to separate the radioactive isotopes from the residual

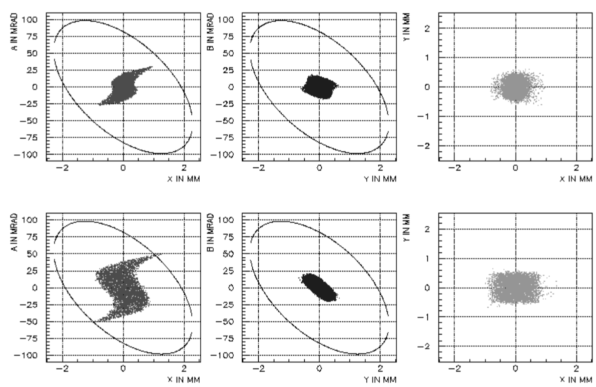

Figure 3: *Phase space and real space of the ion beam at the RFQ entrance. The RFQ acceptance amounts to 200 π mm mrad. The upper figures show the x-x', y-y' and x-y planes for the achromatic system. The lower figures show the result for the magnetic system. The RFQ acceptance ellipse is also drawn. The particles were started with the MONTECARLO method using $x_{max} = 1.5\ mm$ and $x'_{max} = 5\ mrad$ and traced through the COSY INFINITY third order transfer matrix.*

gas ions, also coming out from the REXEBIS and to inject the separated beam into the RFQ accelerator. The small number of radioactive isotopes makes it necessary to calculate the ion optics using a Gaussian beam with 4 standard deviations. Applying this method it is ensured that only 0.01 % of the particles passing through the mass slit are residual gas ions. For the calculations the COSY INFINITY code was chosen. With a MONTECARLO method, a large number of particles could be traced through the third order transfer matrix generated by COSY INFINITY. Depending on the ion beam emittance from the REXEBIS, two separator systems were designed. An achromatic system consisting on the combination of an electrostatic and a magnetic bender reaches the required resolving power of 150 for 2-σ emittances up to $10\ \pi\ mm\ mrad$. In case of higher REXEBIS emittances, a magnetic system was designed, where the beam is bent through two magnetic sector fields. In this beam emittances up to $50\ \pi\ mm\ mrad$ (2-σ) are allowed, but with an energy spread $\leq 0.1\ \%$.
The injection into the RFQ was optimized in third order using a quadrupole doublet and a quadrupole quadruplet. With COSY INFINITY the phase space could be very well fitted into the RFQ acceptance ellipse and a stigmatic beam spot at the RFQ entrance could be produced.
Emittance measurements on the REXEBIS (still in construction) will decide which separator system will be built for REX-ISOLDE.

8 REFERENCES

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