POSSIBLE SCHEME OF THE ANALYZING PART OF A CYCLOTRON INJECTION BEAMLINE WITH HIGHER ENERGY

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Abstract

Ion source extraction potentials are often in the range of 10 - 30 kV where space-charge forces are detrimental to beam quality. Use of higher extraction voltage results in reduced space-charge effects but may be too high for subsequent injection. A scheme of beam extraction at 50 kV followed by deceleration to 25 kV is considered. Simulation results with an argon beam in such a beam line are presented.

INTRODUCTION

A conventional configuration of the early part of an injection line is an electron cyclotron resonance ion source (ECRIS), followed by a focusing solenoid and a double focusing analyzing magnet. The beam accelerated by the ion source potential consists of a mixture of ions charges and types until the desired ion and charge is selected by the analysis magnet. The focal length of the solenoid is chosen to optimize transmission for this desired ion, which in the case at the NSCL has a charge-to-mass ratio of about 1/6. For less-rigid ions (ions with Q/A > 1/6), the focal length is shorter than for ions injected into the cyclotron. Therefore, in the beam line between the solenoid and the analyzing magnet, these less-rigid ion beams have significantly smaller transverse dimensions compared as compared to the dimensions of the injected beam. In the region outside of the less-rigid ion beam boundary, the defocusing self-field decreases as the inverse distance of the ions from the beam axis. For cases where the less-rigid beams have significant intensities, the space-charge of these beams leads to formation of hollow beam shapes after the analyzing magnet and increases injected beam emittance.

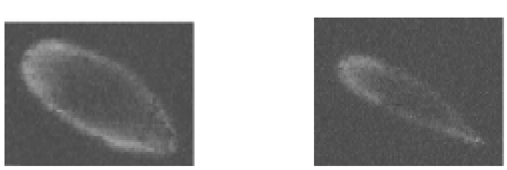

Figure 1. Images of ~100 eμA $^{40}Ar^{+7}$ beam from the NSCL superconducting ECRIS with solenoid focusing. On the left, helium used as a support gas in the source and comprises about 1 emA of the total beam current of 1.8 emA. Shutting off the helium gas supply results in the image on the right; the peak of the argon charge state distribution is 9, so some ring remains.

This effect has been observed both in computer simulation [1] and by experiment in the NSCL injection beam line [2]. The measured and computed $^{40}Ar^{7+}$ beam densities in the NSCL injection beam line are shown in Fig. 1 and 2, respectively.

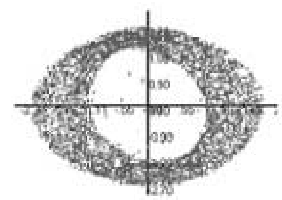

Figure 2. Calculated shape in the (x,y) plane of $^{40}Ar^{+7}$ at a location just after the analysis magnet. With the solenoid, effects of Q/A > 7/40 beams form a ring in x-y space.

Replacing the focusing solenoid with an electrostatic quadrupole triplet eliminates this effect [2]. Unfortunately, initial calculations showed that the diameter of the apertures in such a quadrupole triplet should be about 200 mm to achievee highest transmission efficiency.

An another possibility to reduce the influence of the beam space charge is to increase the kinetic energy W of the ions. This would produce a decrease of the emittance by a factor of $W^{-1/2}$ and the influence of the space charge would decrease as $W^{-3/2}$.

The ion beam produced with an ECRIS with an extraction voltage of 25 kV may be additionally accelerated using a negative voltage of -25 kV applied to the third electrode of the accel-decel extraction system, connected to the vacuum pipe of the beam line biased to the same -25 kV potential. In this way the kinetic energy of the beam is increased to 50 keV per unit charge. The influence of the space charge on the ion beam is decreased two times and it is possible to remove the focusing elements between the ECRIS and the analyzing magnet. Shortening the distance between the ECRIS and the analyzing magnet further reduces the negative effect of the space charge on the ion beam emittance.

The voltage on the vacuum pipe of the beam line must be kept constant from the ECRIS to the image focal plane of the analyzing magnet where full separation of the beam charge states is achieved. A vacuum pipe insulator break separates the biased beam line from the downstream section, which is at zero potential. Passing through this section of the beam line, the ion beam is decelerated to 25 keV per unit charge, the energy necessary for the injection in the K500 cyclotron. In order to limit the increase of the beam divergence due to deceleration, a focusing solenoid is installed behind the break point.

This work presents the results of a simulation of the transport of an argon beam in the proposed beam line. All calculations have been done by using MCIB04 code [3].

BEAM LINE LAYOUT

The scheme of the proposed analyzing part of the injection beam line is shown in Fig. 3. The beam line consists of the longitudinal magnetic field of the ECRIS (ECR), a 90-degrees double focusing analyzing magnet (AM90), and region with decelerating electrical field at the vacuum pipe break (VPB) and focusing solenoid (S). The parameters of the 90-degrees analyzing magnet are presented in Table 1.

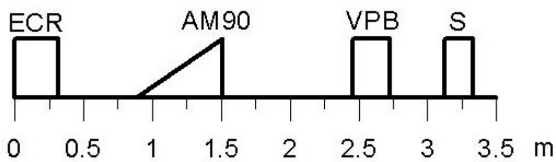

Figure 3. Scheme of the beam line.

Table 1. Parameters of the analyzing magnet AM90.

Bending radius, cm	40
Bending angle, degree	90
Pole face rotation angle, degree	26.5
Bending field ($^{40}Ar^{7+}$, 350 keV) kGauss	1.932

BEAM PARAMETERS

The simulation has been performed for a beam of argon ions. The parameters of the beam are shown in Table 2.

Table 2. Argon beam parameters.

Ion mass	40
Ion charge	2-12
Central (injected) charge	7
ECRIS extraction voltage, kV	50
Kinetic energy (central charge), keV	350
Initial beam diameter, mm	8
Beam emittance (central charge), π mm·mrad	70
Total current, mA	2.31
Central charge current, μA	275

TRANSMISSION EFFICIENCY

The starting point of the simulation is close to the object point of the analyzing magnet. The distance between the starting point and the entrance of the analyzing magnet is equal to 88 cm. The dependence of the transmission efficiency through the bending magnet on the energy per unit charge of the ions in this case is shown in Fig 4.

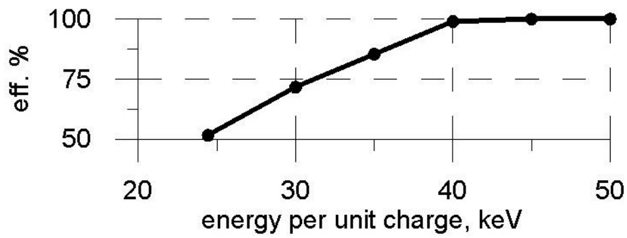

Figure 4. Transmission efficiency. The transmission efficiency is equal to 100% if the energy per unit charge is greater than 45 keV.

The (x,x′) beam emittance and (x,y) particle distribution just after the analyzing magnet are shown in Fig 5. In contrast to the case of lower energy beam transport and using a focusing solenoid placed between ECRIS and analyzing magnet [1,2], there is no nonlinear distortion of the beam emittance and no evidence of hollow beam formation.

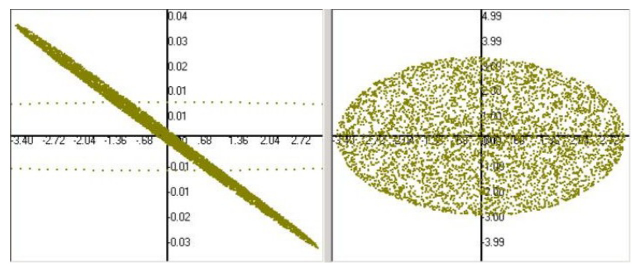

Figure 5. At left is the Ar7+ ion distribution in (x,x′) plane, on the right the (x,y) plane is shown.

VACUUM PIPE BREAK

The negative voltage at the vacuum pipe of the beam line must be kept constant from the ECRIS until the image focal plane of the analyzing magnet. The distance between the exit of the AM90 and the image focal plane is equal to 108 cm. The beam of Ar^{7+} has a crossover at this point. The influence of the electrical field nonlinearity is proportional to $(r/R)^n$, where r is the ion beam radius, R is the vacuum pipe radius, and n is the order of nonlinearity. In the VPB the beam radius is much smaller than the vacuum pipe radius. Therefore the influence on beam emittance of nonlinearities in the electric field arising from the VPB will be insignificant.

The electric field distribution near the VPB has been computed by using the RELAX3D code [4]. A schematic view of the electrodes used in this computation is shown in Fig 6. The gap between electrodes is equal to 3 cm. The electrical field distributions for r=0 and r=2.5 cm are shown in Fig. 7.

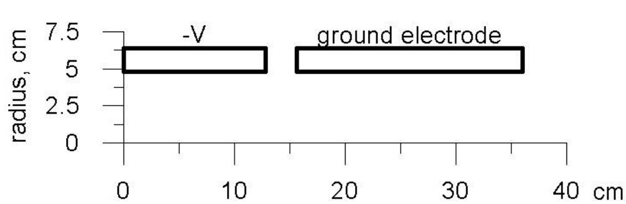

Figure 6. Schematic view of electrodes. V– voltage jump.

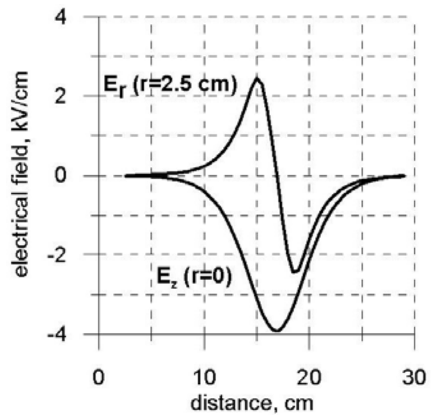

Figure 7. Electrical field distributions. V=25 kV.

FOCUSING SOLENOID

Because of the decelerating field in the VPB region, beam emittance increases. Therefore, after the crossover the beam diameter will increase very fast. In order to decrease beam divergence, a focusing solenoid should be installed just after VPB as shown in Fig. 3. The parameters of such a solenoid may be chosen the same as the existing one in the NSCL injection beam line [2]. By using a moderate magnetic field (maximum magnetic field of the solenoid is equal to 5.5 kG) a slightly converging beam may be formed after the focusing solenoid.

SIMULATION RESULTS

The particle trajectories in the proposed beam line are shown in Fig. 8. The total length of the analyzing part of the injection beam line is about 3.5 m. The envelopes of the $^{40}Ar^{7+}$ beam are shown in Fig. 9. The dependence of the emittance of the beam on transportation distance is shown in Fig. 10.

The growth of the emittance is caused by deceleration of the beam in the VPB region. The nonlinear distortions of the beam shape and emittance are eliminated in the proposed analyzing part of the injection beam line.

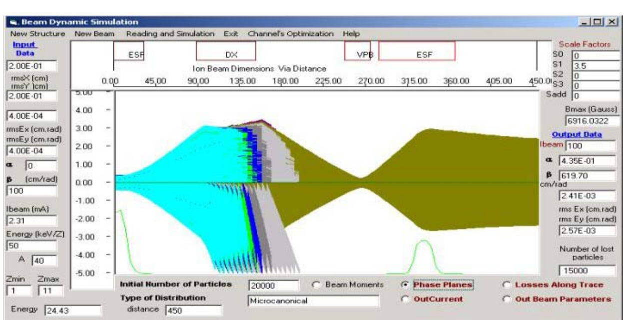

Figure 8. Particle trajectories.

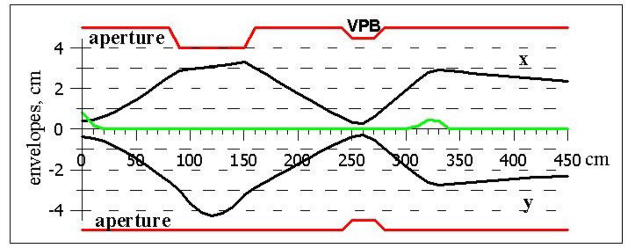

Figure 9. Horizontal (x) and vertical (y) envelopes of the 40Ar7+ ion beam.

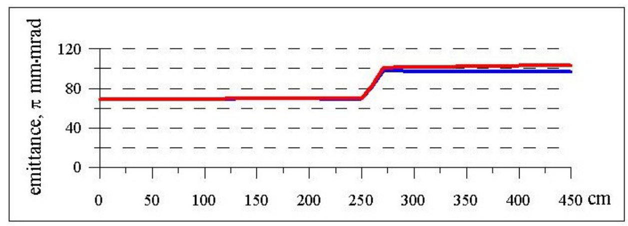

Figure 10. Emittance of the 40Ar7+ ion beam.

ACKNOWLEDGEMENTS

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