INJECTION TRANSPORT LINE OF THE VINCY CYCLOTRON

P. Beličev, B. Bojović, M. Rajčević, Laboratory of Physics, Vinča Institute of Nuclear Sciences, Belgrade, Serbia and Montenegro
N. Yu. Kazarinov, Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, Dubna, Russia

Abstract

The parameters of the injection transport line of the VINCY Cyclotron are determined on the basis of the ion beam transport calculations for three test ion beams: H^- and H_2^+ from pVINIS, and $^{40}Ar^{6+}$ from nVINIS. The ion beam transport calculations were performed using the first-order transport matrix formalism and the TRANSPORT computer code. The space charge effect was taken into account using the BEAMMOMENT computer code. The obtained results imposed the upper limits of the injected ion beam currents due to the space charge widening of the beam envelopes, and determined the design parameters of the ion-optical elements.

INTRODUCTION

The role of axial injection ion beam transport line is to guide the ion beam from the external ion sources, where it is produced, up to the entrance of the spiral inflector device. It has two functions: to constrain the dimension of the beam envelope within the limits of the apertures of the guiding system, and to provide appropriate matching between the beam emittance and cyclotron acceptance. The ion beams injected into the VINCY Cyclotron are produced with two ion sources: the pVINIS Ion Source (multicusp type) and the nVINIS Ion Source (ECR type), which are located below the cyclotron. The following three ion species: H^-, H_2^+ from the pVINIS, and $^{40}Ar^{6+}$ from the nVINIS, were used as representative beams in designing the injection transport line. The ion beam transport calculations were performed using the first-order transport matrix formalism and the TRANSPORT computer code [1]. The space charge effect was taken into account using the BEAMMOMENT computer code [2]. The effects of the buncher and chopper on beam transport have not been considered.

INITIAL PARAMETERS AND FITTING CONDITIONS

The geometry of the injection transport line is depicted in Fig. 1. The ion beam transport starts at the extraction apertures of either the pVINIS (point B) or the nVINIS (point C) ion source, and ends at the entrance of the spiral inflector of the cyclotron (point A). The line comprises a two grid sinusoidal buncher (SB), working in the frequency range from 17 to 31 MHz, and a chopper (CH), working at 150 Hz with a changeable duty factor. A pepper-pot device for decreasing the beam intensity down to about 10%, for beam adjustment at high energies, is also included. Two steering magnets (SM1, SM2), provide proper beam centring on the line. Besides the ion optical elements, the vacuum and diagnostic systems are also shown in the figure. The necessary vacuum of the order of 10^{-7} mbar is maintained by two crio (CP1, CP2) and two turbomolecular pumps (TP1, TP2). The beam current and profile are measured by a Faraday cup (FC) and a beam profile monitor (BPM).

The basic initial parameters of the representative ion beams used for beam transport calculations are given in Table 1. The emittance of the H^- ion beam has been measured, while the values for the rest of the beams are taken as reasonable assumptions. At the starting points all beams have double waists. The data concerning the cyclotron's main coils currents determine the magnitude of the magnetic field along the axis of the lower axial channel in the cyclotron yoke, as well as the fringe magnetic field below the yoke. The magnetic fields for the main coils currents, shown in Table 1, are calculated by the MERMAID computer code [3], from the median plane down to 4 m below the yoke. This magnetic field affects the beam transport along the injection line and should be taken into consideration. For the sake of beam transport calculation, the influence of magnetic field along the lower axial channel of the cyclotron yoke, as well as the fringe magnetic field below the yoke, is modelled by small solenoids whose lengths vary form 5 to 20 mm, depending on the field intensity and variation.

The beam transport calculations were performed under the following constraints and fitting conditions:

1. The beam profile in the region where the longitudinal magnetic field exists (within the axial channel and below the yoke) should be kept as axially symmetric as possible.
2. At the inflector entrance, the relation β_x [mm/rad] = β_y [mm/rad] = $2R_m$ [mm] should hold, and the beam should have double waist ($\alpha_x = \alpha_y = 0$). In the previous relation α and β are Twiss parameters, and R_m is the magnetic radius of the inflector.
3. The beam envelope should not exceed ~80% of the dimensions of the apertures defined by the vacuum chambers within which the beam transport occurs.

The reason for the first condition is to minimize the coupling effect between the transversal phase planes during the beam transport along the line, which is a known effect in the transport of the noncircular beams through solenoidal magnetic fields. The second condition provides minimal oscillations of the beam envelopes inside the spiral inflector. The third condition is quite common for this type of calculations, preventing the beam from interacting with the vacuum chambers of the line.

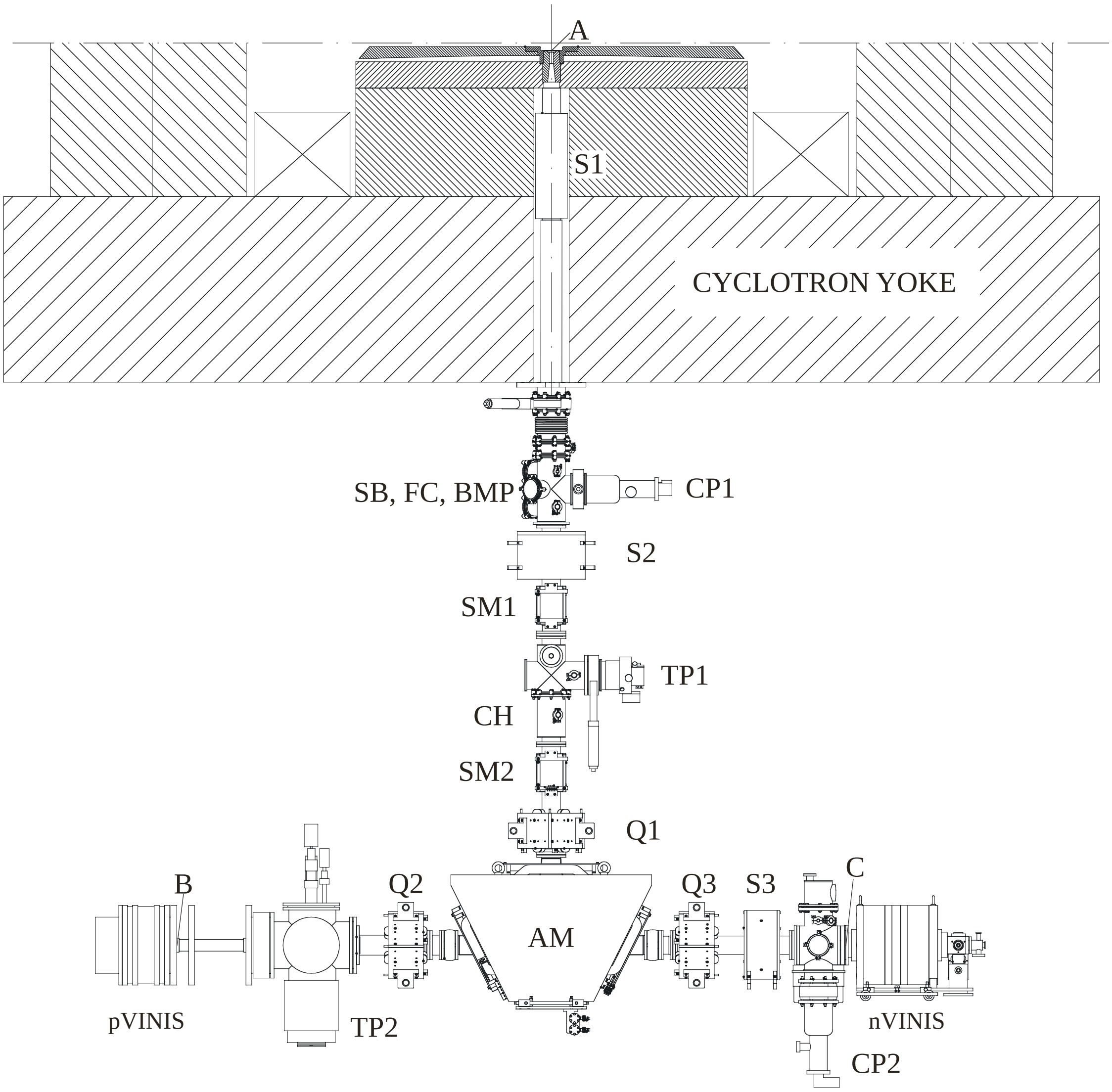

Figure 1: Layout of the injection transport line: A – inflector entrance; B – pVINIS extraction aperture; C – nVINIS extraction aperture; S1, S2, S3 – solenoid lenses, Q1, Q2, Q3 – quadrupole lenses; AM – bidirectional analyzing magnet; SM1, SM2 – steering magnets; SB – sinusoidal buncher, CH – chopper; TP1, TP2, CP1, CP2 – turbomolecular and crio vacuum pumps; FC – Faraday cup; BPM – beam profile monitor.

Table 1: Initial Parameters of the Representative Ion Beams

Ion Species	E_{inj} [KeV]	Cyclotron main coils current [A]	Emittance ε_x, ε_y [π mm×mrad]	Dimensions x_m, $y_m^{\#}$ [mm]	Divergences x'_m, $y'_m{}^{\#}$ [mrad]
H^-	25	257	30	3	10
H_2^+	23	711	60	3	20
$^{40}Ar^{6+}$	87	945	150	7	21.43

[#] x- x' and y- y' designate the two transverse phase planes; x lies in the bending plane of the analyzing magnet AM.

RESULTS

The injection transport line comprises a common part, between point A and the analyzing magnet AM (see Fig. 1), and two branches going to points B and C. Schematically, the lines can be represented as: (BA) d6-Q2-d5-AM-d4-Q1-d3-S2-d2-S1-d1 and (CA) d9-S3-d8-Q3-d7-AM-d4-Q1-d3-S2-d2-S1-d1 respectively, where d1 to d9 designate the drift spaces. The results of the beam transport calculations obtained by the TRANSPORT computer code [1] are given in terms of the beam envelopes diagrams along the corresponding transport lines, with no space charge included. These diagrams are given in Figs. 2 - 4. The inner radius of the beam line guiding tube is 50 mm. The symbols of the ion optical elements in Figs. 1-4 represent only their positions

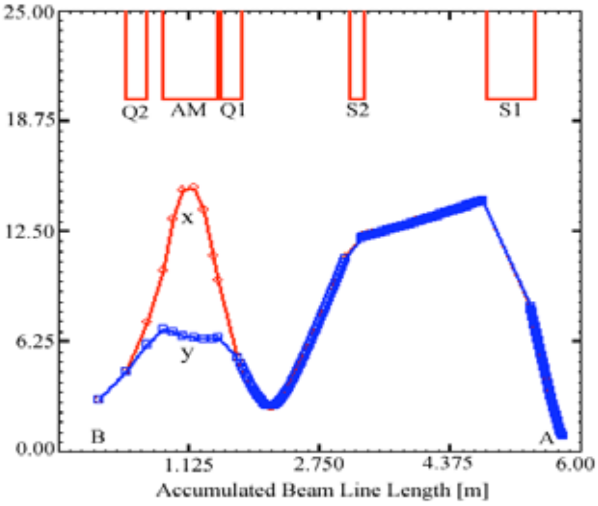

Figure 2: The envelopes of the H$^-$ ion beam, in mm. The initial parameters of the beam are given in Table 1.

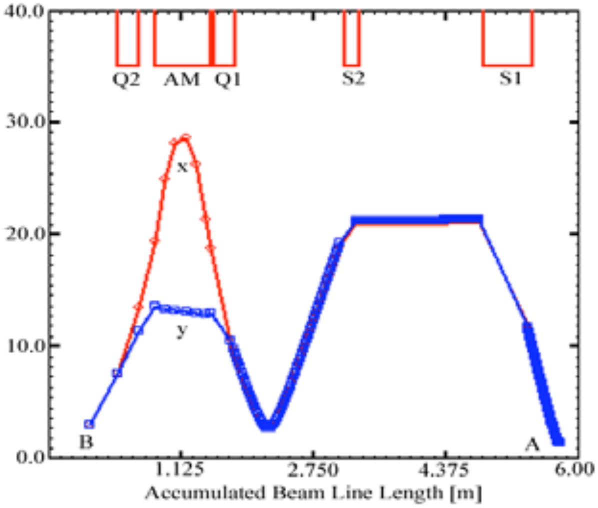

Figure 3: The envelopes of the H2+ ion beam, in mm. The initial parameters of the beam are given in Table 1.

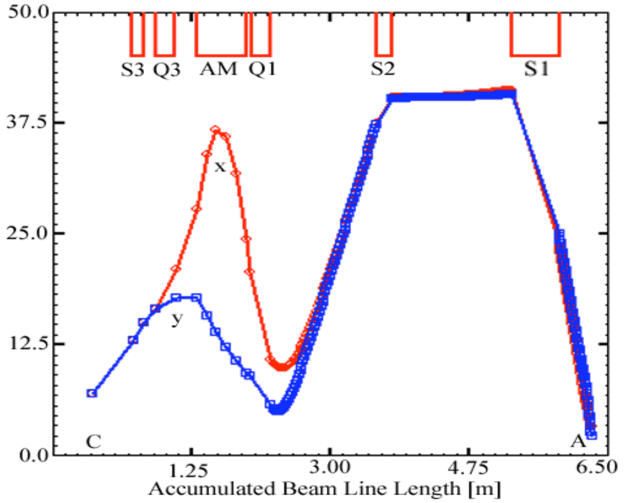

Figure 4: The envelopes of the 40Ar6+ ion beam, in mm. The initial parameters of the beam are given in Table 1.

in the line, while the aperture is artificially decreased for the sake of better visibility. The results showed that only the first and the third fitting conditions are fully met, while the second one can be satisfied only to an acceptable extent.

The values of the main parameters of the ion optical elements, obtained in the calculations, are as follows:

- Bidirectional analyzing magnet AM: bending radius 400 mm, bending angle 90^0, entrance pole face rotation angle 26.6^0, exit pole face rotation angle 0^0, maximal magnetic induction 0.16 T, pole gap 70 mm, good field region ± 40 mm.
- Solenoid lens S1: effective length 600 mm, maximal magnetic induction 0.17 T, good field region ± 40 mm.
- Solenoid lens S2: effective length 193 mm, maximal magnetic induction 0.28 T, good field region ± 40 mm.
- Solenoid lens S3: effective length 134 mm, maximal magnetic induction 0.5 T, good field region ± 40 mm.
- Quadrupole lenses Q1 – Q3: effective length 250 mm, aperture radius 55 mm, maximal magnetic induction gradient 0.6 T/m, good field region 40 mm.
- Effective drift lengths d1 – d9: 405, 1505, 1333, 53, 200, 350, 265, 150 and 513 mm.

In order to estimate the limitations imposed by the space charge effect, additional calculations by the BEAMMOMENT computer code [2] were performed. The results showed that the limiting beam currents that can be injected into the VINCY Cyclotron are equal to about 1.3 mA and 1 mA for H$^-$ and H_2^+ beams, respectively. The limiting currents for the heavy ions are higher than those ones obtainable from the nVINIS source.

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