STATUS OF INJECTION TRANSPORT BEAM LINE AT KERNFYSISCH VERSNELLER INSTITUTE

by

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At Kernfysisch Versneller Institute, optical properties of injection transport beam were studied. Measurements of beam size and emittance determined by "varying quadrupole method" are compared with calculations including fringe fields up to the third order with the COSY INFINITY code. Calculations and measurements qualitatively match; the calculations reflect the observed large beam losses. On the basis of the calculations new settings have been determined, resulting in a significant increase of the transmission. To achieve full transmission a complete redesign of the beam line is needed, in particular of the bending magnets.

Key words: beam, transmission, fringe field, emittance, quadrupole

INTRODUCTION

Low energy beam line between electron-cyclotron-resonance (ECR) source [1] and AGOR-cyclotron is shown in fig. 1. The beam current of $^3He^+$ion just after the analyzing magnet M110 (see fig. 1) is about 20 A but after the matching section (matching section consists of five electrostatic quadrupoles; from EQ8 to EQ12 in fig. 1) is only 2 μA. In order to improve the transmission of the beam through injection beam line beam emittance should be known [2]. The beam emittance is measured at three different positions along the beam transport line and in both planes, horizontal and vertical, by varying the strength [3] of an upstream quadrupole [4, 5]. The first horizontal/vertical profile grid (marked by letters HH1/HV1 in fig. 1) is located 7.17/7.27 m downstream from the ion source, the second profile grid (HH2/HV2) is located 10.20/10.30 m and the third one (HH4/HV4) is located 15.40/15.41 m down stream from the ion source.

Optical properties of this transport beam line are determined by using COSY INFINITY code [6] in the third order of approximation taking into account the effects of the fringe fields also in the third order of accuracy.

Data from the profile grids are digitized, acquired and processed by Control System. For each setting of the strength of an upstream quadrupole the profile data are fitted into Gauss distribution [4, 5].

The estimated values of emittance and its corresponding error at different profile grid positions along the transport beam line are presented in tab. 1. This is considered to be the case when half beam profile is equal to 2.35 $_{ST}$, where $_{ST}$ is the standard deviations of the Gauss distribution. Characteristics of the $^3He^+$ beam are: kinetic energy, T_k = 8.33 keV/n, magnetic rigidity [3], $B\rho$ = 0.0394 Tm, electrostatic rigidity [3], χ_E = 0.05 MV. The length of each electrostatic quadrupole is 12 cm and half of their aperture is 5 cm.

We can see from tab. 1 that emittance slightly grows in the horizontal plane along the transport beam line and in the case of the vertical plane the emittance suddenly takes-off at the HV4 profile grid position. The cause of increasing beam emittance and beam losses as the beam propagates downstream are dispersion and aberrations at least of the third order (see, for example, ref. [3], Section 5). The cause of very high value of beam emittance at HV4 profile grid can be the strong effects of

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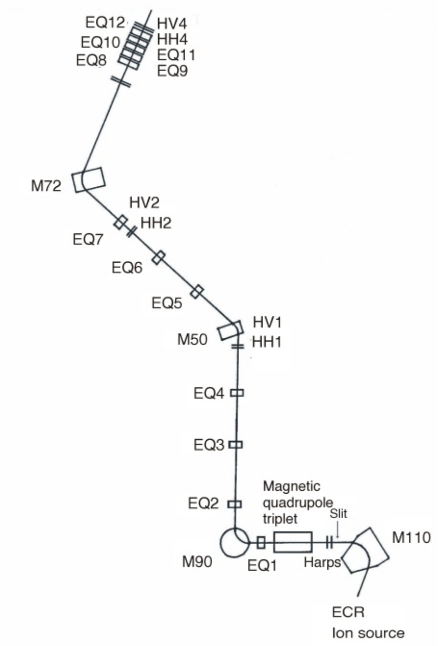

Figure 1. Layout of low energy beam line at the AGOR-facility

fringe fields in the matching section. The fringe field effects are not taken into account in emittance measurement by varying the strength of an upstream quadrupole [4, 5].

COSY CALCULATIONS

Present settings of the optical elements

Measurements of the beam current and emittance along the beam line exhibit large beam losses observed through the transport beam line. The losses of the beam through the transport line can be presented by using COSY INFINITY too by calculating the beam envelope.

Optical properties of low energy beam line at the AGOR-facility are studied for $^3He^+$ beam. It is considered to be the case of $\varepsilon_x = 30$ mm mrad and $\varepsilon_y = 40$ mm mrad for beam emittances in the horizontal and vertical plane, respectively (see tab. 1) and 0.5% momentum spread at half width [3, 7].

Table 1. The estimated values for emittance and its corresponding error at different profile grid positions along transport beam line

$^3He^+$	$V_{ex} = 25$ kV	
Profile's grid position	ε_x [mm mrad]	ε_y [mm mrad]
HH1 & HV1	28 2	42 5
HH2 & HV2	37 1	54 1
HH4 & HV4	52 1	190 10

Table 2. Characteristics of bending magnets installed at low energy beam line at AGOR-facility

Characteristics of bending magnets	M110	M90	M50	M72
Bending radius, ρ_0 [cm]	40	24	29	24
Bending angle, [degree]	110	90	50	72
Half aperture width, a [cm]	3.5	3	3	3
Entrance pole face angle, ε_1 [degree]	37	0	15.63	30
Exit pole face angle, ε_2 [degree]	37	0	15.63	30
Entrance curvature, h_1 [1/cm]	0	0	0	0
Exit curvature, h_2 [1/cm]	0	0	0	0

Beams from the ECR source are analyzed for charge state by a M110 bending magnet and transported by a magnetic quadrupole triplet and an electrostatic quadrupole EQ1 to a M90 bending magnet (see fig. 1). Characteristics of M110 and the M90 bending magnets are shown in tab. 2. The bending magnet M110 is double focused with focal length of about 53 cm. This distance has been chosen as object point for transport calculations. The analyzing magnet M110 can separate ion beams with mass-to-charge ratio differences of 1.2% or more [7]. If needed (for example for separation of $^{131}Xe^{18+}$ and $^{132}Xe^{18+}$) slit width after M110 magnet should be decreased. Beam line section from the slit to the entrance of the M90 magnet is designed to transfer beam waist-to-waist and waist-to-parallel in the horizontal and the vertical plane, respectively. The electrostatic quadrupole EQ1 will match the beam phase space to the acceptance of the M90 magnet. After the M90 magnet the next three electrostatic quadrupoles guide the beam to the M50 bending magnet. This magnet bends the beam by 50 degrees to the left and then the beam is guided by the next three electrostatic quadrupoles up to a M72 bending magnet which bends it by 72 degrees to the right. Characteristics of the M50 and the M72 bending magnets are presented in tab. 2.

After the M72 magnet and after a long drift space (210 cm) comes the matching section which consists of five electrostatic quadrupoles. After the matching section the beam is bent up by 90 degrees by an electrostatic deflector into the cyclotron.

Beam envelopes, calculated by COSY INFINITY code, are presented in the fig. 2 (up-vertical plane, low-horizontal plane). The vertical lines (marked by letter H) in fig. 2 mark the positions of the profile grids.

From fig. 2 (upper part) we can see that the beam is over focused in the vertical plane by the M72 bending magnet. For those settings of the quadrupoles (tab. 3 – old settings column) the

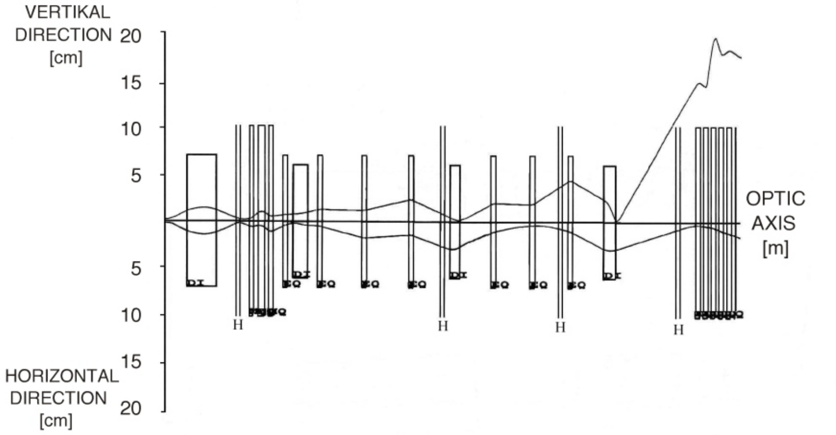

Figure 2. Envelopes of the beam for the old settings of quadrupoles calculated by COSY INFINITY code in the horizontal (low) and the vertical (up) plane. Vertical lines marked by letter H mark the positions of the profile grids

M72 bending magnet is the origin of low transmission through low energy beam line.

New settings of optical elements

On the basis of the calculations, new settings have been determined (tab. 3 – new settings column). Before the presentation of the results of the new settings we will turn our attention to the matching section. The matching section consists of five electrostatic quadrupoles. Half of the aperture and the length of each of them are 5 cm and 12 cm, respectively. The distance between each of them is only 8 cm. The consequence of this geometry is that fringe field effects in this region are very strong. One of the ways to decrease the fringe field effects in the matching section is to remove one of these electrostatic quadrupoles; EQ9, EQ10 or EQ11 (see fig. 1). Now the matching section consists of four electrostatic quadrupoles. The beam envelopes for this case are presented in fig. 3 (up – vertical plane; low – horizontal plane). The new settings of the quadrupoles significantly increase the beam transmission; the new measured value for the beam current after matching section is now 6 A. In addition to everything else the optimization of optical elements of low energy beam line decreases the value of the momentum dispersion.

Table 3. The values of the magnetic induction (in Tesla) and electrode potentials (in kV) of the quadrupoles for the old and the new settings. In case of the old settings the last five quadrupoles make the matching section (figs. 1 and 2). In the case of the new settings the matching section consists now of the four quadrupoles (fig. 3)

Mark of the magnetic quadrupole (magnetic triplet)	Old settings of the quadrupoles [*T*]	New settings of the quadrupoles [*T*]
MQ1	0.0850	0.0850
MQ2	–0.0685	–0.0685
MQ3	0.870	0.0870
Mark of the electrostatic quadrupole	Old settings of the quadrupoles [kV]	New settings of the quadrupoles [kV]
EQ1	–0.150	–0.150
EQ2	–0.232	–0.232
EQ3	+0.214	+0.214
EQ4	–0.322	–0.370
EQ5	–0.303	–0.400
EQ6	+0.374	+0.374
EQ7	–0.300	–0.180
EQ8	–0.388	–0.700
EQ9	+1.138	+0.500
EQ10	–1.182	---------
EQ11	+0.466	–0.466

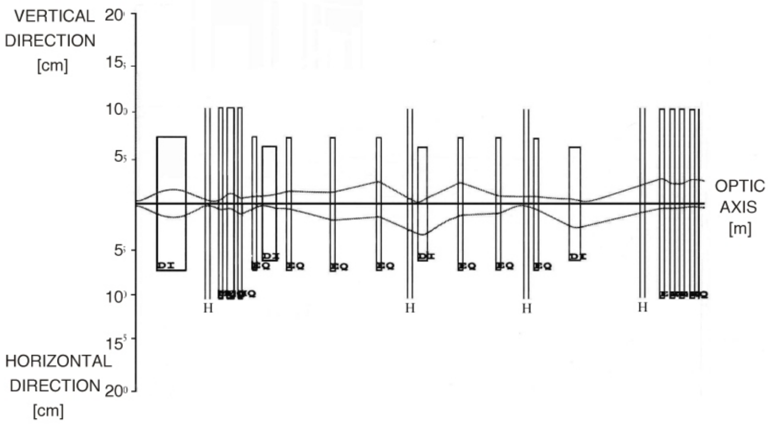

Figure 3. Envelopes of the beam for the new settings of quadrupoles calculated by COSY INFINITY code in the horizontal (low) and the vertical (up) plane. Vertical lines marked by letter H mark the positions of the profile grids

CONCLUSION

Measurements of beam profiles and prediction of beam emittance at different positions along the transport beam line and calculations of beam envelopes by using COSY INFINITY code in the third order of approximation together with the effects of the fringe fields of optical elements in the third order of accuracy show that, in case of low energy beam line at AGOR-facility, beam transmission can be increased by new settings of the quadrupoles. To achieve full transmission, complete redesign of the beam line, in particular of the bending magnets, is needed.

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СТАТУС ИНЈЕКЦИОНЕ ТРАНСПОРТНЕ ЛИНИЈЕ СНОПА У ИНСТИТУТУ ЗА НУКЛЕАРНА ИСТРАЖИВАЊА У ГРОНИНГЕНУ

У овом раду су испитивана оптичка својства инјекционе транспортне линије снопа у Институту за нуклеарна истраживања у Гронингену. Резултати мерења профила снопа и његове емитансе, чија је вредност процењена методом промене потенцијала на електродама квадрупола, упоређени су са прорачунима која су урађена програмом COSY INFINITY укључујући и ефекте крајева све до трећег реда апроксимација. Прорачуни и мерења се квалитативно слажу да постоји велики губитак интензитета снопа. На основу резултата теоријских прорачуна нов скуп вредности карактеристика оптичких елемената снопа је предложен, а резултат тога је значајно повећање трансмисије снопа. Да би се постигла потпуна трансмисија снопа потребно је извршити комплетан редизајн транспортне линије, а нарочито обратити пажњу на скретне магнете у њој.