BEAM TRANSPORT DESIGN FOR THE LINAC SYSTEM IN THE INS RADIOACTIVE BEAM FACILITY

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Abstract

A low-energy beam transport (kinetic energy = 2 keV/u, charge-to-mass ratio $\geq 1/30$) before a 25.5-MHz split coaxial RFQ and a medium-energy beam transport (170 keV/u, charge-to-mass ratio $\geq 1/10$) between the RFQ and a 51-MHz interdigital-H linac have been designed. These linacs are to be set up in the INS radioactive beam facility. The low-energy beam transport is designed to obtain a momentum resolution high enough to distinguish Al^+ ions from N_2^+ ions. We have carried out a beam trace from an ion source to the entrance of the interdigital-H linac. The aberration of einzel lenses, the non-linear rf defocusing force in bunchers and the various effects of a charge stripper are taken into account. We study the emittance growths in these transports. Especially in order to make a longitudinal emittance small, a prebuncher at the upstream from the RFQ is proposed. The longitudinal 90% rms emittance at the entrance of the interdigital-H linac is improved by a factor of 3 by using a harmonic prebuncher.

Introduction

Exotic-nuclei arena (E-arena) project, which aims at the acceleration of the unstable nuclei beams from an isotope separator on-line (ISOL), is proposed in the Japanese Hadron Project (JHP). A prototype E-arena project at Institute for Nuclear Study has been proceeding since 1992. We are constructing two linacs: a 25.5-MHz split coaxial RFQ (SCRFQ) [1] and a 51-MHz interdigital-H (IH) linac [2]. The former accelerates unstable nuclei from 2 keV/u up to 170 keV/u, and the latter from 170 keV/u up to 1 MeV/u at maximum. The minimum charge-to-mass ratio (q/A) is 1/30 at the SCRFQ and 1/10 at the IH linac; hence, a charge stripper is necessary. However, the charge stripping causes to increase both transverse and longitudinal emittances. The longitudinal acceptance of the IH linac is only 3 times as large as the emittance of the SCRFQ output beam [3]. So a prebuncher at the upstream from the SCRFQ is proposed. For reducing the defocusing force in the prebuncher, a focus point with a beam radius less than 1 cm must be designed.

In this paper at first we report the design procedure of the low-energy beam transport (LEBT) before the SCRFQ and present some results of a beam trace through the LEBT. Secondly, the review of the medium-energy beam transport (MEBT) between the SCRFQ and the IH linac is mentioned [3,4] and the results of a beam trace from an ion source to the entrance of the IH linac are presented. Finally, this paper is summarized.

Low-Energy Beam Transport

The LEBT, which transports a beam from a conventional ion source (IS), consists of a 90° bending magnet (B), four einzel lenses (E1-4) and two quadrupole magnets (Q1-2). This transport is for beam tests of the linacs. Figure 1

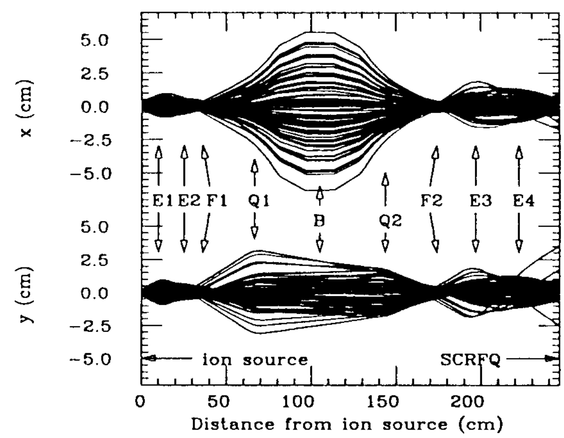

Figure 1: The calculated ion trajectories in the LEBT.

indicates the calculated ion trajectories in the LEBT. The radioactive beam from the ISOL will be matched at F2 to join this transport. The bending magnet is used for the discrimination of ions with different charge-to-mass ratios. The quadrupole magnets are used for making the vertical beam size small in the bending magnet and to take a matching in the transverse phase space. At F1 and F2, the beam is focused to a circular spot. The proposed prebuncher will be located at F2.

Beam parameters for a matching

The emittance of the beam from the IS is supposed to be 29.1 π cm · mrad (the normalized one is 0.06 π cm · mrad). This value is almost one order greater than that of the beam from the ISOL. The acceptance of the SCRFQ is large in comparison with these emittances [5]. The ellipse parameters to be matched in a transverse phase space are listed in Table 1. The exit of the IS is supposed to be a hole with

TABLE 1
Ellipse Parameters in x-x' and y-y' Spaces

	β (cm)	α	ε (π cm · mrad)
IS-out	1.377	0.0	29.1
RFQ-in	17.99	0.813	29.1

4 mmϕ. The ellipse parameters at the entrance of the SCRFQ is calculated by the GENRFQ code. The transmission of the SCRFQ is about 92% for a dc beam with 29.1 π cm $\cdot$ mrad.

Principle of the design

The principle of the fundamental design of the LEBT is as follows: 1) to obtain a good matching between the IS and the SCRFQ, and 2) to make a focus point at the upstream of the SCRFQ. In order to obtain a good matching, an aberration of einzel lenses must be suppressed. As the focusing strength is fixed by the beam size at the focus points, the balance of each einzel lens is important. At F2 the beam must be focused to a spot with a radius of $\leq$1 cm so as to weaken the rf defocusing force and to improve the transit time factor of the prebuncher. Through a beam dynamics study in the SCRFQ, we found a good longitudinal-output emittance is obtained with a prebuncher located at about 70 cm upstream from the SCRFQ. This focus point is also necessary to discriminate ions with different charge-to-mass ratios by using a bending magnet together. The bending magnet is designed to obtain a momentum resolution which is sufficiently high to distinguish Al^+ ions from N_2^+ ones.

Procedure for a matching

In order to optimize the parameters of the LEBT components, we divide the LEBT into three parts with boundaries at the two focus foints F1 and F2. After optimizing in each region, we connect these three regions. Consequentry, we found a solution with the focus spots of a radius 4 mm. The F2 is at 64 cm upstream from the SCRFQ. The einzel lenses are supplied with about 40 kV for $q/A = 1/30$ ions. The field gradient and the bore radius of quadrupole magnets are 6.488 kG/cm ($q/A = 1/30$) and 4.6 cm, respectively. As for the bending magnet, the field strength, the gap height, the radius of curvature and the bending angle are 6.44 kG ($q/A = 1/30$), 6 cm, 30 cm and 90 deg, respectively.

Results of the LEBT

The transverse beam profiles at the entrance of the SCRFQ are shown in Fig. 2. The solid lines indicate the ellipses with emittances of 29.1π cm $\cdot$ mrad with the parameters in Table 1. About 73% of the particles from the IS are contained in both of the x-x' and y-y' ellipses. The prebuncher is switched off in Fig. 2; when switched on, the emittance profiles change little.

The x-x' beam profile at F2 are shown in Fig. 3(a). The parameters of the LEBT are optimized for Al^+($q/A = 1/27$) ions. N_2^+($q/A = 1/28$) ions are assumed as background. We see Al^+ ions can be distinguished from N_2^+ ions. The difference between the momenta of $q/A = 1/27$ ions and 1/28 ones is 1.85%. A calculated dispersion η of 124 cm is consistent with the result of Fig. 3(a). Consequentry, it gives the momentum resolution of 0.65%. When the beam with a larger emittance from the IS is injected, the x-x' profile at F2 is shown in Fig 3(b). The discrimination becomes a little worse. In any case this resolution is high enough to distinguish Al^+ ions from N_2^+ ones.

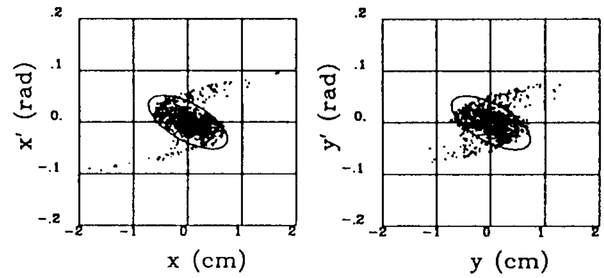

Figure 2: The transverse profiles at the RFQ entrance.

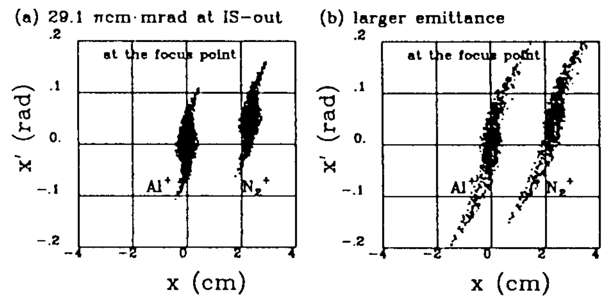

Figure 3: The transverse profiles at F2 (at prebuncher). The LEBT parameters are optimized for Al^+ ions.

A beam trace in the LEBT with the prebuncher was also taken. The prebuncher is a harmonic buncher operating at 25.5 MHz. This prebuncher consists of two gaps with a gap length of 4 mm and a bore radius of 7 mm. The field distribution in the prebuncher was calculated by the SUPERFISH. In order to take a trace in the prebuncher, the procedure of the trace with the filed distribution and the rf phase are installed into the TRACEP code [6]. Finally we carried out a simulation up to the entrance of the IH linac. The resultant beam emittances in the longitudinal and the transverse phase space are discussed in the next section.

Beam Trace from the IS to the IH

The longitudinal phase space of the beam from the SCRFQ has a shape of whirl; we define the emittance by the ellipse including this profile as an emittance. The IH linac has an acceptance with a shape of a boomerang; we define the effective acceptance by the ellipse that inscribes the boomerang and has the largest area. As the results, the transverse and longitudinal emittances from the SCRFQ are estimated to be about 3.1 π cm $\cdot$ mrad and 75 π keV/u $\cdot$ deg without the prebuncher, while the acceptances of the IH linac are 12.4 π cm $\cdot$ mrad and 200 π keV/u $\cdot$ deg, respectively [3].

The designed MEBT (170 keV/u, $q/A \geq 1/10$) comprises a charge stripper, a rebuncher and two quadrupole doublets. This transport system has a total length of 3.76 m. In order to contain the beam in the acceptance of the IH linac, the frequency of the rebuncher is determined to be 25.5 MHz. As the rebuncher, a double-coaxial resonator with 6 gaps has been designed to maintain the size small and power low [7].

We have studied several issues concerning the stripper and the rebuncher. The stripper and rebuncher distort the transverse and longitudinal beam profiles. With regard to the stripper, such effects as increase of the charge state, energy loss, straggling, and multiple scattering were studied [4]. We carried out a beam trace by taking into account these effects in the TRACEP code. In a case of a $^{12}C^{+}$ beam, about 50% of the ions becomes 3+ ions after a carbon stripper having a thickness of 10 $\mu g/cm^2$ [8]. The radial-position dependencies of the defocusing force and transit time factor of the rebuncher were also taken into account. These effects cause the emittance growths in the stripper and the rebuncher. The beam trace from the IS to the entrance of the IH linac is performed. The beam simulation in the LEBT and the MEBT is performed using the TRACEP code, in the SCRFQ using the PARMTEQ code.

90% rms emittances

Figure 4 shows the longitudinal profiles at the entrance of the IH linac for the following four operation conditions: (prebuncher, stripper) = (off, off), (off, on), (on, off), and (on, on). A thousand ions are generated at the IS.

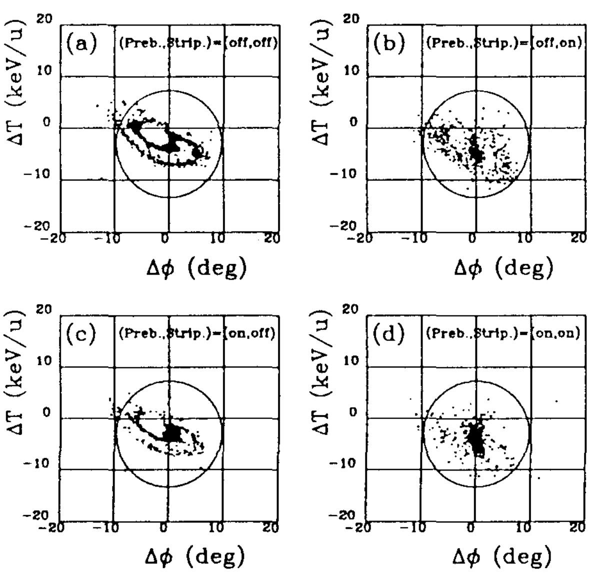

Figure 4: The longitudinal profiles at the IH entrance. The MEBT parameters are optimized for $^{12}C^{3+}$ ions. (T_0 = 172.133 keV/u, Freq. = 25.5 MHz)

The solid lines indicate the acceptance ellipses of the IH linac. The 90% rms emittances corresponding to each figure are listed in Table 2. Although the stripper causes the emittance growth by a factor of 1.33 (=8.499/6.391), the emittance reducing-rate by the prebuncher is about 0.40 (=3.396/8.499). Especially without the stripper the emittance reducing-rate is about 0.32 (=2.016/6.391). Moreover, the particle density in the core around the null point is enhanced by a factor of 10. The transverse emittances are listed in Table 3. Besides the stripper the rebuncher also causes the increase of the transverse emittances. Since this increase is caused by the defocusing force which is non-linear in terms of the rf phase, the prebuncher is effective in reducing the transverse emittance growth also.

TABLE 2
Longitudinal 90% rms Emittances (π keV/u · deg)

	(Preb.,Strip.)	RFQ-out	IH-in	number of particles
(a)	(off, off)	6.371	6.391	734
(b)	(off, on)	6.371	8.499	410
(c)	(on, off)	2.035	2.016	781
(d)	(on, on)	2.035	3.396	434

TABLE 3
Transverse 90% rms Emittances (π cm · mrad)

	(Preb.,Strip)	RFQ-out		IH-in	
		x-x'	y-y'	x-x'	y-y'
(a)	(off, off)	.4538	.4960	.5385	.4920
(b)	(off, on)	.4538	.4960	.7230	.5277
(c)	(on, off)	.4445	.4671	.4787	.4634
(d)	(on, on)	.4445	.4671	.6531	.5243

Summary

The design studies of the LEBT and the MEBT are finished. Notwithstanding the aberration of the einzel lenses, The ≥73% of the injected ions from the IS is transmited through the SCRFQ. The bending magnet at the LEBT can sufficiently distinguishes q/A = 1/27 ions from 1/28 ones. As the results of the trace from the IS to the entrance of the IH linac, the effectiveness of the prebuncher is demonstrated.

Acknowledgments

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