Nuclear Instruments and Methods in Physics Research A 788 (2015) 13–23

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Design study of low energy beam transport line for ion beams of the post-accelerator at RAON

Yumi Lee, Eun-San Kim *

Department of Physics, Kyungpook National University, Daegu 702-701, Korea

ARTICLE INFO

Article history:
Received 21 December 2014
Received in revised form
17 March 2015
Accepted 18 March 2015
Available online 27 March 2015

Keywords:
Low energy beam transport
Heavy-ion accelerator
Pair solenoid
Multi-harmonic buncher

ABSTRACT

Low-energy ions produced by the ion source pass through the focusing and acceleration sections. During this process, the ions accumulate energy and are finally transported to the apparatus that utilizes them for a specific purpose. Thus, in order to increase the transmission efficiency of the ion beams, the low energy beam transport (LEBT) system must minimize the beam loss and the emittance growth. The LEBT system is designed and optimized to transmit $^{132}Sn^{16+}$ and $^{58}Ni^{8+}$ beams of the post-accelerator at RAON that is the accelerator complex for the rare isotope science. The post-accelerator LEBT line comprises solenoids and electrostatic quadrupoles for transverse focusing and a multi-harmonic buncher for longitudinal focusing. This paper presents the results of the optical design and beam tracking for the post-accelerator LEBT obtained by using TraceWIN and TRACK codes.

1. Introduction

The abbreviation RAON represents the rare isotope accelerator of newness at the rare isotope science project (RISP), as the major research facility of the international science business belt (ISBB) in Korea. The RAON accelerator complex comprises a heavy-ion linear accelerator called the Driver Linac as the driver for the in-flight fragment (IF) system, a proton cyclotron as the driver and a post-accelerator for the isotope separation on-line (ISOL) system [1]. Fig. 1 presents the schematic layout of the RAON accelerator. As a part of RAON at RISP, the LEBT in the post-accelerator is designed from the exit of the ion source to the entrance of the radio frequency quadrupole (RFQ).

As shown in Fig. 1, the post-accelerator LEBT line has two different ion source systems. One is the ISOL system that produces the Sn ion beam. The mass-to-charge state ratio (A/Q) of the Sn ion beam with a low kinetic energy of 5 keV/u is 8. The other one is an 18 GHz normal-conducting electron cyclotron resonance ion source (ECR-IS) system. The ECR-IS system produces the Ni ion beam with a low kinetic energy of 5 keV/u. The A/Q of the ion beam is 7.25. Therefore, the main purpose of the LEBT system is to maintain the high transmission efficiency of the two different types of ion beams from the ion sources to the RFQ. In addition, the minimization of the costs and the possibility of the actual manufactures should be considered. In this paper, the transmission status of the beams and performance of the LEBT design for the post-accelerator are presented.

2. Transverse and longitudinal focusing elements

As shown in Fig. 2, the post-accelerator LEBT comprises the transverse and longitudinal focusing elements. The abbreviations PS, BM, ESQ, MHB and S represent a pair of solenoid magnets, an analyzing bending magnet, an electrostatic quadrupole magnet, a multi-harmonic buncher, and a single solenoid magnet, respectively.

The MHB is a longitudinal focusing element. The purposes of the buncher are to reduce the growth of the longitudinal emittance and to improve the bunching efficiency of the RFQ [2]. Figs. 3–5 indicate the behaviors of the longitudinal bunching of the beams by a buncher with a single frequency and three frequencies. In the case of the single frequency buncher, as shown in Fig. 3(a), the voltage function with respect to time is a type of sine-wave. Thus, the particles in the range of approximately -90° to 90° are bunched. The bunching efficiency becomes 50%. Therefore the slope of the sine-wave between the up-peak and the down-peak must be as long and straight as possible to improve the efficiency. Thus, 1, 0.351, and 0.115 are determined as the synthesis coefficients used in the MHB with three frequencies. Fig. 3(b), (c) and (d) shows the voltage function according to the time variation for the case of bunchers with two, three and four frequencies, respectively. Fig. 3(b) shows that the scope of the bunching is extended up to $\pm 100^{\circ}$. Fig. 3(c) and (d) presents the voltage functions of the

* Corresponding author.
E-mail address: eskim1@knu.ac.kr (E.-S. Kim).

http://dx.doi.org/10.1016/j.nima.2015.03.054
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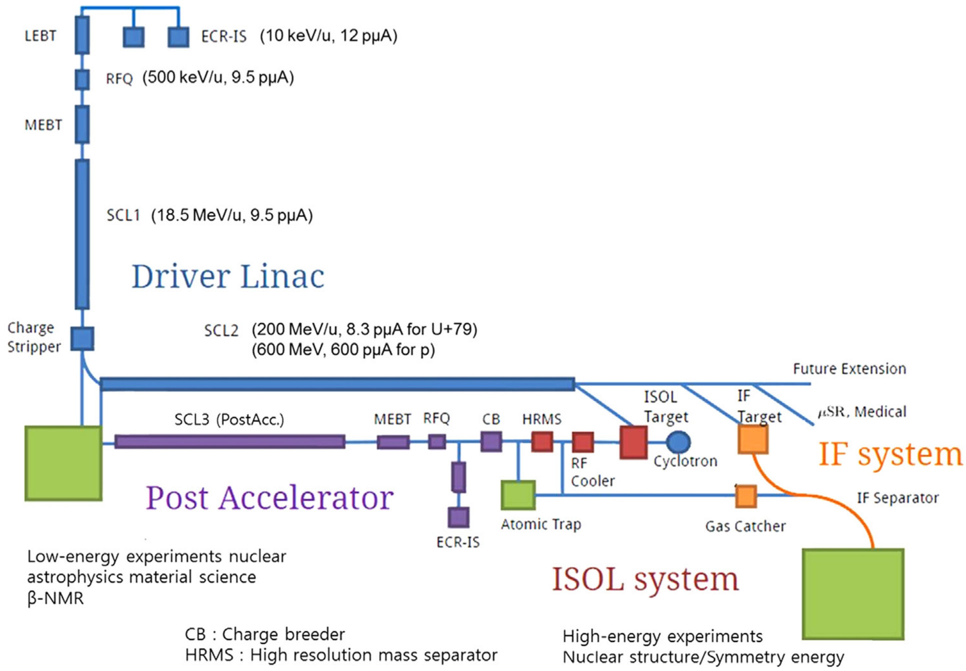

Fig. 1. The layout of the RAON accelerator.

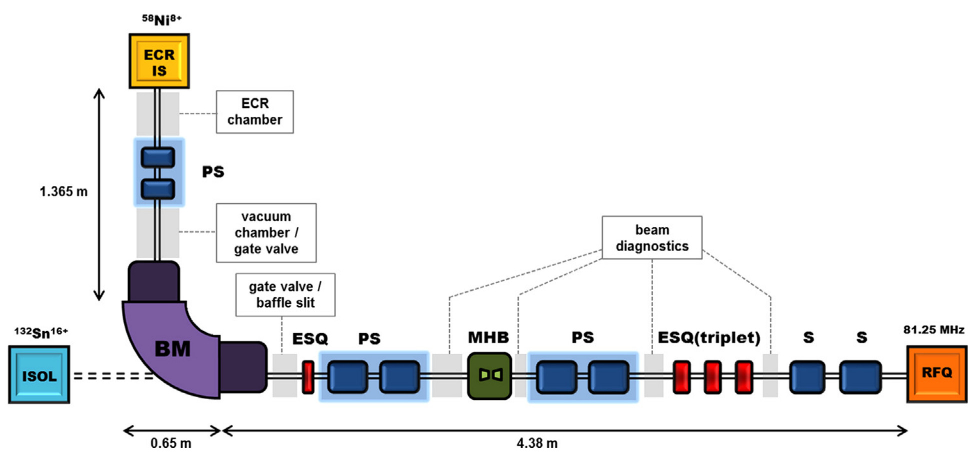

Fig. 2. The LEBT scheme of the post-accelerator.

sawtooth-wave form with a straight slope. In this case, the particles in the range of approximately -125° to 125° are bunched, and the bunching efficiency may be better.

Fig. 4 indicates the Ni ion beam distributions for the single and multi-harmonic buncher by using TRACK simulation code. Fig. 4(a) represents the Ni ion beam distribution after passing through the single buncher at 81.25 MHz which is the same frequency as that of the RFQ. Fig. 4(b), (c), and (d) represents the Ni ion beam distributions after passing through the multi-harmonic buncher with two, three and four frequencies, respectively.

Fig. 5 shows the bunched Ni ion beam distributions according to the frequency at the entrance of the RFQ using TRACK simulation code. In the case of a single buncher, as shown in Fig. 5(a), the bunching efficiency is 68.9% between $\pm 60^{\circ}$. At the same phase range, the bunching efficiencies for the two, three and four harmonic bunchers are approximately 79.5%, 81.7% and 81.8%, respectively. Thus, the use of the multi-harmonic buncher with three frequencies in post-accelerator LEBT is determined because of the bunching efficiency. The triple multi-harmonic buncher is operated at 81.25, 162.5 and 243.75 MHz. Fig. 6 shows the distribution of the electric field used in the MHB simulation. The aperture radius of the electrode and the distance between the electrodes were 2 and 4 cm, respectively. The total length of the MHB was 28 cm. The voltage of the electrodes operated for the electric field shown in Fig. 6 was 5 V. Each electric field was generated by using the voltage amplitude multiplied by a scale factor.

The remaining elements, except for the MHB, are transverse focusing elements. The components of the transverse lens are as follows: a pair of solenoids immediately after the ECR-IS extraction, a 90° analyzing bending magnet, an electrostatic quadrupole, two different pairs of solenoids, electrostatic quadrupole triplet and different single solenoids.

The design of the analyzing bending magnet is the same as the one in the main accelerator LEBT system for the convenience of manufactures and reduction in cost [3]. The sector type bending magnet with a radius of 65 cm is used. The ECR-IS produces not only Ni^{8+} but also Ni ions with other charge states. In the analyzing bending magnet, the beam separation occurs according to the particle momentum difference, depending on the charge states. Therefore, baffle slits are expected to be installed at the end of the bending magnet.