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Room temperature quarter wave resonator re-buncher development for a high power heavy-ion linear accelerator

Hye-Jin Kim *, B.H. Choi, Jaeeun Han, Myung Ook Hyun, Bum-Sik Park, Ohryoung Choi, Doyoon Lee, Kitaek Son

RISP, Institute for Basic Science, Daejeon 305-811, Republic of Korea

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ABSTRACT

In the medium energy beam transport (MEBT) line system of the RAON which consists of several quadrupole magnets, three normal-conducting re-bunchers, and several diagnostic devices, a quarter wave resonator type re-buncher was chosen for minimizing longitudinal emittance growth and manipulating a longitudinal phase ellipse into the longitudinal acceptance of the low energy linac. The re-buncher has a resonant frequency of 81.25 MHz, geometrical beta (β_g) of 0.049, and physical length of 24 cm. Based on the result of numerical calculations of electromagnetic field using CST-MWS and mechanical analysis of the heat distribution and deformation, an internal structure of the re-buncher was optimized to increase the effective voltage and to reduce power losses in the wall. The criteria of the multipacting effect was estimated and it was confirmed by the experiment. The position and specification of cooling channels are designed to recover a heat load up to 15 kW with reasonable margin of 25%. The coaxial and loop type RF power coupler are positioned on the high magnetic field region and two slug tuners are installed perpendicularly to the beam axis. The frequency sensitivity as a function of the tuner depth and cooling water temperature is measured and the frequency shift is in all cases within the provided tuner range. The test with a high power of 10 kW and the continuous wave is performed and the reflection power is observed less than 450 W.

1. Introduction

The Rare Isotope Science Project (RISP) is launched to construct a high-power heavy-ion accelerator based on a superconducting linear accelerator in Korea. The accelerator named as RAON will provide ion beams from proton to uranium beam with various energy range and beam power of up to 400 kW [1–3] for a multidisciplinary research. The RAON accelerator consists of a front-end system, a low energy linear accelerator (linac), a charge stripping section, a high energy linac, an in-flight separator, and low and high experimental systems. The front-end system of RAON which consists of an electron cyclotron resonance (ECR) ion source, a low energy beam transport (LEBT) line, a radio frequency quadrupole (RFQ) accelerator, and a medium energy beam transport (MEBT) line is produced and delivered ion beams from proton to uranium into the low energy linac [4]. The MEBT line is installed between the RFQ accelerator and the low energy linac, to match optical parameters in transverse planes and to remove unaccelerated ion beam fractions from the RFQ accelerator. The MEBT line has a long straight section for a future injector upgrade which can produce a high power deuteron beam with the beam energy of 2 MeV/u. It also includes beam diagnostic devices to measure and control beam qualities and Twiss parameters at the entrance of the low energy linac during nominal beam operation. The layout of the MEBT line of the RAON is shown in Fig. 1.

The position and number of quadrupole magnets and re-bunchers are optimized to accept and control the transverse and longitudinal distributions of various ion beams such as a 500 keV proton beam and 500 keV/u ^{238}U and ^{18}Ar beams [5,6]. In addition, the component in the MEBT line should be enabled for the high power deuteron beam line with beam currents of up to 15 mA and the beam energy of 2 MeV/u, relativistic beta (β_{beam}) of 0.069. From the particle tracking simulation, the first re-buncher should be closed to the RFQ accelerator to prevent the longitudinal emittance growth since the ion beam is quickly divergent due to the large energy spread at the exit of the RFQ accelerator and it can cause beam losses in the linac. The three quarter wave resonator (QWR) type re-bunchers with a resonant frequency of 81.25 MHz and geometrical beta (β_g) of 0.049, and eight room-temperature quadrupole magnets scheme were chosen for high

* Corresponding author.
E-mail address: hjkim87@ibs.re.kr (H.-J. Kim).

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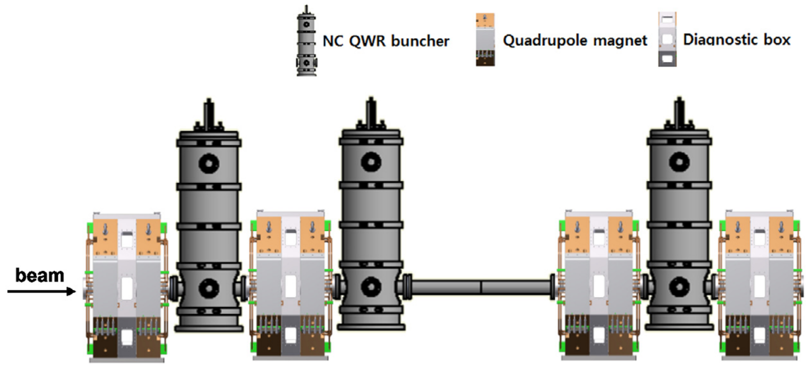

Fig. 1. Layout of the MEBT line which consists of eight quadrupole magnets, four diagnostic boxes, and three re-bunchers. It has a straight section for a future injector upgrade for high power deuteron beam with beam energy of 2 MeV/u.

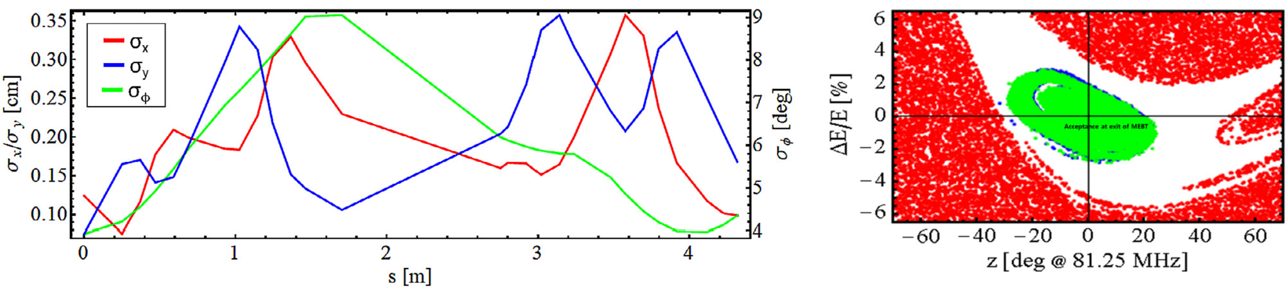

Fig. 2. (left) Transverse and longitudinal beam envelopes of $^{238}U^{33+}$ and $^{238}U^{34+}$ beams in the MEBT line. (right) Longitudinal acceptance of low energy linac and particle distribution at the entrance of low energy linac.

flexibility of the tuning of transverse and longitudinal beam parameters at the entrance of the low energy linac. The transverse and longitudinal beam envelopes of$^{238}U^{33+}$ and$^{238}U^{34+}$ beams in the MEBT line and the longitudinal acceptance of the low energy linac and longitudinal phase space distributions at the entrance of low energy linac are shown in Fig. 2.

In the next section, we introduce the baseline design from the electromagnetic simulation and estimation of multipacting effects of 81.25 MHz quarter wave resonators (QWR) re-buncher using CST-MWS. The optimization of cooling channels by analyzing the heat distribution, mechanical deformation, and stress analysis is also included. In Section 3, we report on the design of a high power coupler and slug tuners for the re-buncher. Based on the numerical calculation, the size, position, and movable range of the tuners are determined to reduce the reflected RF power due to the frequency shift caused by the temperature variation and beam loading effects. Section 4 contains the fabrication and assembly process and RF measurement results of the re-buncher. Finally, our conclusion is given in Section 5.

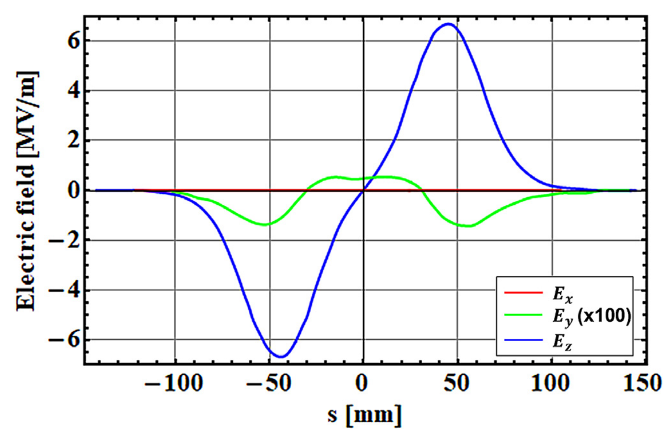

Fig. 3. Electric fields of the designed cavity along the beam axis with constant stored energy of 1 J.

2. Normal-conducting QWR re-buncher design

Based on the results of the optics design and particle tracking simulation, the requirement of a peak electric field on the beam axis, E_0, is calculated to be about 1 MV/m for 0.5 MeV/u uranium beam and about 2.6 MV/m for 0.5 MeV proton and 2.0 MeV/u high power deuteron beams to compensate the emittance growth in MEBT line and to match the longitudinal phase ellipse on the acceptance of the low energy linac. In order to satisfy the limited space and required electric field amplitude, a normal conducting two gap QWR with a frequency of 81.25 MHz and geometrical beta of $\beta_g = 0.049$, corresponding to a beam energy of 500 keV/u, were chosen to provide high electric field for the longitudinal matching of ion beams from the RFQ accelerator into the low energy linac [7]. The distance between the center of two gaps is 9 cm that is consistent with the $\beta_g \lambda/2$ condition. The aperture of the re-buncher is increased to 5 cm from the previous design presented in Ref. [5] to minimize the uncontrolled beam loss inside the cavity. It was limited by a shunt impedance for getting a high effective acceleration gradient. The internal structure, such as shape of the stem, the center sphere, and the beam port, are also optimized to increase the shunt impedance and to decrease the surface electric field which strongly related with the heat loss of the cavity. The electric fields along the beam axis of the designed cavity are shown in Fig. 3 [8].

The re-buncher has the vertical electric field component which can cause orbit steering. It is due to a structural asymmetry of the re-buncher. The effect of the vertical electric field, however, is ignorable because the number and position of steering magnets are defined well to compensate the orbit steering in the MEBT line. In order to estimate the required power to achieve the peak electric field on the beam axis of 2.6 MV/m and the heat capacitance of cooling channels, the parameters of the re-buncher are calculated using CST-MWS code [8]. The shunt