THE STATUS OF THE MSU RE-ACCELERATOR (ReA3)*

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Abstract

The Re-accelerator ReA3 [1] being developed at the Michigan State University is a major component of a novel system proposed to first stop the high energy Rare Isotope Beams (RIBs) created using Coupled Cyclotron Facility (CCF) by the in-flight particle fragmentation method in a helium filled gas system, then increase their charge state with an Electron Beam Ion Trap (EBIT) charge breeder, and finally re-accelerate them to 3 MeV/u to provide opportunities for an experimental program ranging from low-energy Coulomb excitation to transfer reaction studies of astrophysical reactions. The accelerator system consists of a Low Energy Beam Transport (LEBT) with an external multi-harmonic buncher, a radio frequency quadrupole (RFQ), a superconducting linac, and a High Energy Beam Transport (HEBT). The superconducting linac will use quarter-wave resonators with β_{opt} of 0.041 and 0.085 for acceleration and superconducting solenoid magnets for transverse focusing. The paper will discuss the recent progress of R&D and beam dynamics studies for ReA3.

INTRODUCTION

Isotope Separation On-line (ISOL) and Projectile Fragmentation (PF) are the two methods used to produce high quality RIBs for the nuclear science. Since 1989, the NSCL has been using the PF method with great success to produce fast RIBs for nuclear structure and nuclear reaction experiments, especially after the completion of the CCF and the A1900 Fragment Separator in 2001. For ReA3, RIBs from the EBIT will have an initial energy of 12 keV/u and an initial emittance of 0.6 π mm-mrad. The ReA3 is required to accelerate RIBs with charge-to-mass ratios (Q/A) ranging from 0.2 to 0.4 and to achieve a final energy ranging from 0.3 to 3 MeV/u. The nuclear astrophysics experimental program requires the beam bunch width and the energy spread for the RIBs on the experiment target within 1 ns and 1 keV/u, respectively, which corresponding to a small longitudinal emittance of ~0.25 π keV/u-ns. The ReA3 accelerator system consists of four segments: a Low Energy Beam Transport (LEBT) system to transport, bunch and match the RIBs from the EBIT to the RFQ, an RFQ for initial beam acceleration and focusing, a superconducting linac system for RIBs acceleration to the desired energy, and a High Energy Beam Transport (HEBT) system to deliver the RIBs to an experimental area with the required beam parameters. The entire ReA3 accelerator system will be located on a balcony in the NSCL high bay area.

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LEBT

The ReA3 LEBT will transport, bunch and match RIBs from the EBIT into RFQ. An electrostatic triple Bender is implemented in the LEBT in order to allow a stable ion source (SIS) on a high voltage platform to deliver $^4He^{1+}$ beam into the RFQ for SC linac tuning and diagnostics calibrations. It is also capable to deliver RIBs from the EBIT directly to a low energy experiment area as well as accept RIBs from a possible 2nd EBIT in the future upgrade. Figure 1 shows the layout of the ReA3 LEBT. Electrostatic quadrupoles and a solenoid magnet are used to provide transverse focusing for both RIBs and stable beam. In addition, there are four beam diagnostics stations in the LEBT for proper beam transverse and longitudinal matching into the RFQ. To achieve a small longitudinal emittance, an external Multi-Harmonic Buncher (MHB) is used in the LEBT, which has been constructed and tested at MSU recently [2].

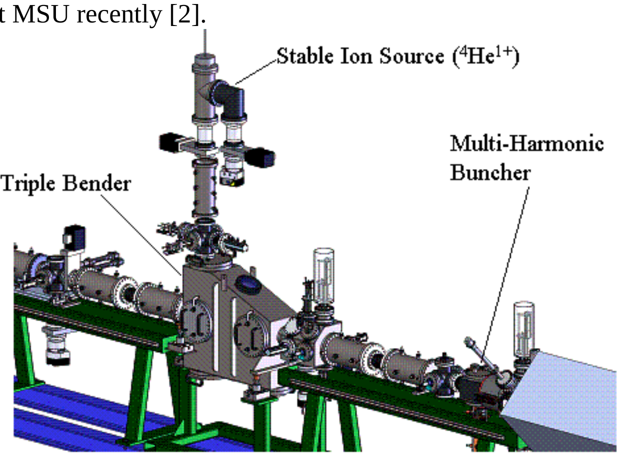

Figure 1: The layout of the ReA3 LEBT.

Figure 2 shows the structure of the triple bender. It consists of three 75° spherical benders and two 15° parallel plate kickers. The spherical bender has a bend radius of 250 mm and a gap of 80 mm. For a maximum initial accelerating voltage of 60 kV, potentials of ±19.2 kV are required to bend beam by 75°. The parallel plate kicker has a gap of 120 mm, and requires potentials of ±9.3 kV to deflect beam by ±15°. Herzog shunt plates grounded to the vacuum chamber are used for limiting the fringe electric fields at the entrance and exit of the electrodes. A gap of 12 mm separates the shunt plates and the electrodes. COSY INFINITY [3] and SIMION [4] were used for beam simulations and optimizations of the shape of the electrodes and the shunt plates.

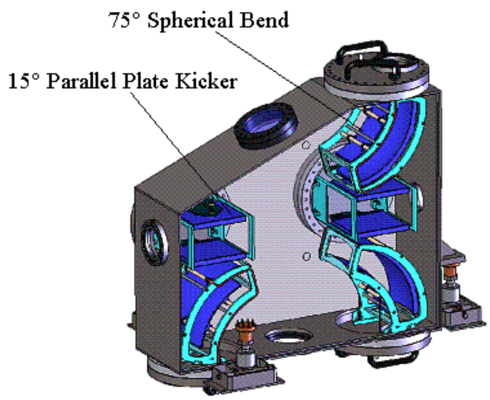

Figure 2: The structure of the triple bender in LEBT.

The beam simulations for RIBs from the EBIT and the $^{4}He^{1+}$ beam from the stable ion source were performed and results show both were well matched transversely and longitudinally into the RFQ. Figure 3 shows the beam envelopes in the LEBT. The triple bender was active only for the stable beam.

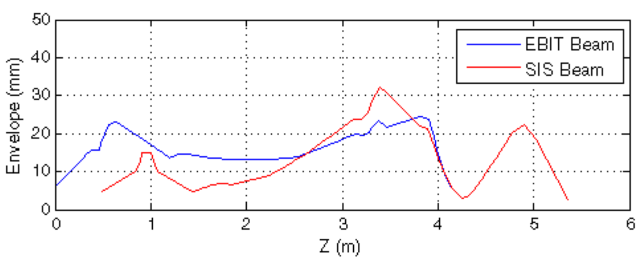

Figure 3: Beam envelopes in the LEBT for RIBs from the EBIT and He beam from the stable ion source.

RFQ

The ReA3 RFQ [5] will accelerate RIBs from 12 keV/u to 600 keV/u with a Q/A ratio of 0.2 to 0.4. The 4-rod structure, CW, room temperature RFQ is currently under design and construction at Frankfurt University [6]. Table 1 lists the main parameters of the RFQ. Together with the external MHB in the LEBT, the ReA3 RFQ will achieve a 90% longitudinal emittance of ~0.29 π keV/u-ns in order to meet the beam requirement for ReA3. The transmission efficiency of the RFQ is about 82%. The RFQ will have an Aluminum tank and improved cooling channels. The delivery of the RFQ, and initial RF and beam tests are expected in 2009.

Table 1: Main RFQ Parameters

Frequency (MHz)	80.5
Length (m)	3.5
Mid-cell radial aperture (mm)	7.3
Vane tip radius (mm)	6.0
Inter-vane voltage (kV)	86.2
Peak field ($E_{kilpatrick}$)	1.6
Peak electric field (MV/m)	16.7

SUPERCONDUCTING LINAC

The ReA3 superconducting linac will provide the acceleration or deceleration of the RIBs from RFQ output energy of 600 keV/u to the desired final energies ranging from 0.3 to 3 MeV/u on target. The SC linac consists of a total of three cryomodules with fifteen 80.5 MHz λ/4 SRF cavities. Eight superconducting solenoid magnets inside cryomodules will provide the transverse focusing. Each solenoid will have two dipole coils to provide alignment error corrections. Figures 4 and 5 show the structures of the λ/4 SRF cavities and the layout of cryomodules of the ReA3 SC linac. Four beam diagnostics stations located in the warm region between cryomodules will be used for beam and SC linac tuning.

Figure 4: λ/4 SRF cavities used in ReA3 SC linac.

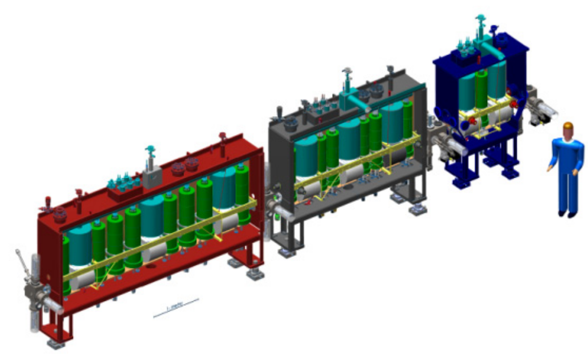

Figure 5: The layout of the cryomodules of the ReA3 SC Linac.

Both λ/4 SRF cavities have been prototyped and tested at MSU, and the RF test results show both cavities exceeding the design field levels by a comfortable margin. A prototype cryomodule consisting of a 80.5 MHz β_{opt} = 0.085 λ/4 cavity and a 322 MHz β_{opt} = 0.285 λ/2 cavity, with helium vessels made of titanium, was fabricated and tested at the NSCL recently. The superconducting focusing magnets inside the cryomodule consist of a 9 T solenoid with an integrated steering dipole and a 31 T/m quadrupole. In addition, a coaxial probe-type rf fundamental power coupler for both λ/4 SRF cavities and a prototype niobium tuning plate for β_{opt} = 0.041 cavity been designed, fabricated and tested at MSU. The detailed test results for the prototype cryomudule, tuner and power coupler will be discussed in separate papers [7, 8].

HEBT

The REA3 HEBT will transport RIBs from the SC linac to the experiment area. Figure 6 shows the layout of the proposed HEBT for ReA3. Two achromatic bending sections were used to bring RIBs from the mezzanine floor to the ground floor while limit the beam emittance growth. A cryomodule with a single λ/4 SRF cavity with β_{opt} = 0.041located between the achromatic bending sections was used to rotate the beam longitudinal phase space, minimizing the final beam energy spread in order to achieve the required beam bunch width and the energy spread for the RIBs on the experiment target within 1 ns and 1 keV/u.

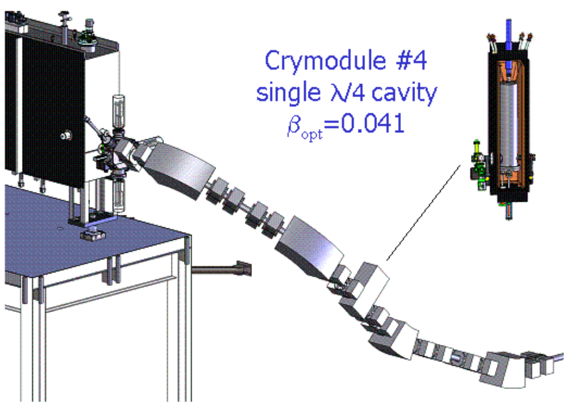

Figure 6: The layout of the ReA3 HEBT.

The beam envelope in the SC linac and HEBT for RIBs accelerated to 3 MeV/u with a Q/A of 0.25 is shown in Figure 7. Beam simulations show that the performance for the RIBs decelerated to ~300 keV/u was similar. About ~88% of beam on target was found to be within the required bunch width and energy spread.

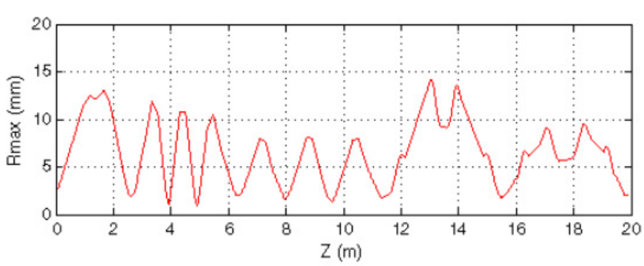

Figure 7: Beam envelope in the SC linac and HEBT.

BEAM DIAGNOSTICS

Many of the beam diagnostic devices for ReA3 are similar to those in use at the ISAC-II accelerator at TRIUMF [9, 10]. They are deployed in various combinations at four diagnostic stations in the LEBT, and the other four in the SC linac section. Because of intensity requirements, many of the devices are usable only with a stable ion beam from either the stable ion source in the LEBT or the EBIT. The preliminary tuning of the RFQ and SC linac will be performed using such a stable beam of the same charge-to-mass as the RIBs.

A movable slit plate containing a vertical and a horizontal slit can be scanned through the beam to provide transverse beam profiles using the beam current registered on the Faraday cup behind it. A phosphor viewer plate is used in diagnostics stations in the LEBT to display the beam cross section. A series of grids for attenuation of the beam current may be inserted if needed to control the stable ion beam intensity. There is provision for installing an emittance rig in one of the diagnostics stations in the LEBT. A 2-dimensional Allison type scanner similar to those used in the CCP injection line will be used for initial beam studies for ReA3.

Downstream from the MHB in the LEBT, there are up to 5 diagnostics stations where a high-resolution timing detector [9] can be used to characterize the longitudinal phase space distribution of the beam and to measure the beam velocity. The beam particles release secondary electrons from a biased coaxial wire inside a metal cylinder, some of which are detected by a multi-channel plate behind a hole in the cylinder wall. The time structure of the beam is directly indicated by the time distribution of the electrons. In addition, up to four scattered particle monitors [10] based on Si heavy ion detectors measuring the energy of elastically scattered beam from a thin gold foil.

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