# DESIGN STATUS OF THE RISP TEST FACILITY LEBT*

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### *Abstract*

Raon, the rare isotope accelerator of the Rare Isotope Science Project (RISP) in Daejeon, South Korea, is being designed to accelerate multiple-charge-state beams simultaneously. Using an Electron Cyclotron Resonance (ECR) Ion Source to produce the ions, Raon will transport the beam through two 90-degree bending magnets and a Low Energy Beam Transport (LEBT) system to a Radio Frequency Quadrupole (RFQ). In order to test the components of the injector and LEBT system, a test facility is under development. A new LEBT, based upon the LEBT of the main driver linac, is being designed to fit within the test facility's restrictive space requirements. This work will briefly review the main driver linac LEBT design, and then discuss the current status of the test facility LEBT design.

## INTRODUCTION

The Institute for Basic Science (IBS), located in Daejeon, South Korea, was established in 2011 by the Korean government. It is the parent organization for many research institutions, one of which is the Rare Isotope Science Project (RISP), which was officially established in the same year as IBS. The following year, the planned accelerator complex for RISP was named Raon, which is a Korean word that means joy or happiness.

The goal of RISP is to produce a variety of stable and rare isotope beams which can be used in a variety of basic scientific research and applications. The final energy of the beams at Raon will be 200 MeV/u. Unlike other rare isotope facilities, Raon will produce isotopes using both In-Flight (IF) fragmentation and Isotope Separation On-Line (ISOL) methods. To accomplish this, the IF system uses a driver linac which consists of two superconducting ECR ion sources, a low energy beam transport (LEBT) section, a 300 keV/u RFQ, a medium energy beam transport (MEBT) section, a 18.5 MeV/u superconducting linac, and a charge stripper. The ISOL system uses a proton cyclotron as the driver.

This work will focus on the LEBT section of the driver linac. The authors will first briefly describe the basic layout and design aspects of the LEBT for the driver linac. The remainder of this work will describe the current state of the design for a modified, shortened LEBT, which will be used in a test facility that is to be installed within a year

## FACILITIES

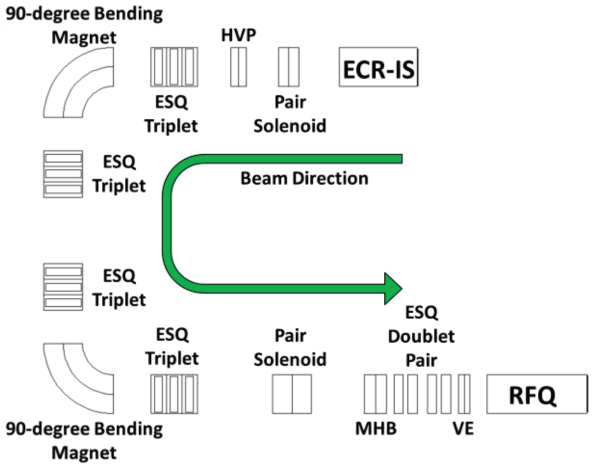

Figure 1: Main Driver Linac

### *The Driver Linac*

The driver linac, shown in Figure 1, begins with a superconducting ECR ion source. The maximum extraction voltage from the ECR is 30 kV. Particles that are extracted from the ECR are then focused through a pair solenoid, and if further acceleration is required, the particles will pass through a high-voltage platform. The beam then enters into an electrostatic lattice, beginning with an electrostatic quadrupole (ESQ) triplet. Following the triplet, the beam passes through a 90-degree bending magnet, which separates out various charge species. The remaining beam then goes through an achromatic electrostatic beamline consisting of two electrostatic quadrupole triplets and diagnostic equipment. Another 90-degree bending magnet is used to keep the lattice achromatic for multi-beam transport. From here, the beam passes through an electrostatic matching section, including a multi-harmonic buncher and velocity equalizer, and is matched into an RFQ.

### *The Test Facility*

As production of the RFQ and ECR progresses, a test facility is under development for the purposes of testing the RFQ and ECR. Additionally, components of the LEBT and control systems will be tested in this facility. The site chosen for the test facility is nearby the current IBS location. However, the dimensions of LEBT test facility are too small for the current design of the LEBT and a beam dump. In order to accommodate the size limitations, the length of the test facility LEBT must be reduced.

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The test facility LEBT should remain the same as the driver linac LEBT as much as possible; it must be achromatic, the beam size must remain adequately small, and the beam must properly match into the RFQ. To both meet the beam requirements and accommodate the size restraints, changes were made to the final matching section of the LEBT, which starts immediately after the second bending magnet.

The radius of the LEBT beam pipe is 6 cm. However, to avoid introducing nonlinearities into the beam dynamics, the maximum beam size must remain much smaller than this 6 cm limit. The beam must remain achromatic as it is transported from the ECR to the RFQ. In order to match into the RFQ, the beam must reach a beam energy of 10 keV/u, and have Twiss parameters of α = 0.3241635 and β = 5.6743681 cm/rad.

## SIMULATIONS

### *Codes Used*

Using the main driver linac as a guide, TRANSPORT was used to design a baseline, zero-current limit, first-order achromatic model of the test facility LEBT. Before the matching section, the beamline dimensions remained the same as in the main LEBT, though the component strengths were varied according to necessity.

Sometimes, the final matching into the RFQ is not adequate using TRANSPORT. In these cases, the matching section is simulated in Trace 3-D. Since the matching section in the test facility LEBT is short, matching in this section is easily accomplished in Trace 3-D. Using the beam parameters at the beginning of the matching section, and the beam parameters required to match into the RFQ, Trace 3-D's matching function provides fast and accurate results.

Taking the baseline models from TRANSPORT and Trace 3-D, conversions are made and the values of the beamline components are then entered into TRACK. Occasionally, minor adjustments are required, but the beamline found through TRANSPORT is almost the same as that produced in TRACK. Differences usually occur where the two codes differ in treatment, especially in places where TRACK uses field maps of elements, such as the high-voltage platform. Final matching for the baseline model is performed in TRACK, with special focus on the final matching section. Once a baseline model has been found with no space charge, space charge is then introduced and matching performed.

### *Simulation Procedure*

For the test facility, a Bismuth-209 beam with a +29 charge state is used for the model, as the A/q value is similar to that of Uranium-238 +33, which is used in the main LEBT design. The LEBT simulation begins at the exit of the ECR, where a 4D waterbag distribution is used. This is only a baseline approximation, as the actual beam exiting the ECR will be triangular and be rotating due to sextupole terms in the ECR. The initial beam parameters are shown in Table 1.

Table 1: Input Beam Parameters

| Parameter | Value |
|---|---|
| Extraction Voltage | 30 kV |
| HVP Voltage | 42 kV |
| $\epsilon_{RMS,Normalized,Total}$ | 0.12 π-mm-mrad |
| $\alpha_x$ | 0 |
| $\alpha_y$ | 0 |
| $\beta_x$ | 10.38 cm/rad |
| $\beta_y$ | 10.38 cm/rad |
| Beam radius at ECR exit | 0.5 cm |

These are converted to the necessary terms for each of the simulation codes.

In TRANSPORT, several matching parameters were used throughout to make sure the beam remains achromatic through the LEBT. The lattice must remain mirror symmetric about the center of the bending section, and the net dispersion in the bending section must be zero.

The beam was also matched into the RFQ. TRANSPORT makes this process relatively simple, and provides a good baseline model for the remaining simulations. However, TRANSPORT often lacks the accuracy required to match into the RFQ. Thus, using the beam parameters from TRANSPORT at the end of the second bending magnet as the input parameters in Trace 3-D, a more accurate matching solution can be found. When converted back into TRANSPORT and appended to the end, a baseline simulation can be produced.

This beamline is used as the baseline for the TRACK simulation. The dimensions and component strengths are converted into TRACK units, and a simulation is performed in the zero current limit. Adjustments are then made to clean up any small errors, and TRACK is run again. If the matching in the RFQ is not accurate, the matching section is simulated separately in TRACK, and once a result is obtained with a reasonable accuracy, the matching section is appended to the rest of the beamline, and the TRACK simulation is completed in the zero current limit.

Once the zero current limit simulation has been accomplished, space charge is added to the TRACK simulation, and adjustments are made to compensate for the space charge effects.

Once space charge effects are addressed, one can investigate multiple-charge-state beams. This is important, since Raon will produce multiple species and multiple charge states simultaneously in its ECR.

### *Current Simulation Results*

For the test facility LEBT, several solutions have been tested for the matching section. Since the test facility will not have a MHB or a velocity equalizer, and

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the matching section should be as short as possible while still having space for diagnostic equipment, we began with simple solutions. The goal of these tests was to show a proof-of-principle. We wanted to show that it is possible to design a shortened LEBT that would minimize beam loss, retain an adequately small beam size, and match into the RFQ.

The first attempt at matching used a pair of electrostatic quadrupole doublets (Figure 2). This made the overall length of the LEBT 9.922 m, down from the 12.692 m of the original LEBT. While this solution was able to match the beam into the RFQ, the beam size in both planes was too large, even in the zero current limit. Once space charge was introduced, there was non-negligible beam loss in the final matching section.

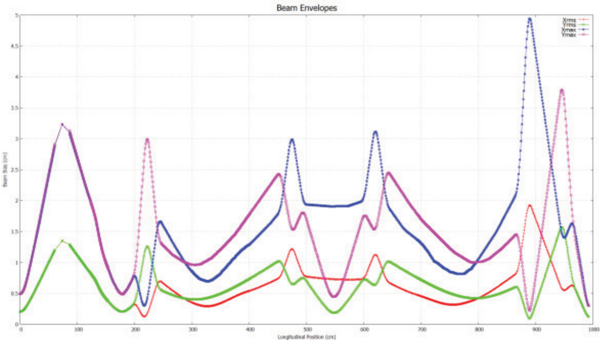

Figure 2: 2 ESQ Doublets. Red and green are RMS X and Y beam sizes; blue and pink are max X and Y beam sizes, respectively. Ordinate is beam size, ranging from 0-5 cm. Abscissa is longitudinal beam position from 0-1000 cm.

Next, an additional electrostatic quadrupole pair was added near the first pair, for a total of three electrostatic quadrupole doublets (Figure 3). The new quadrupoles replaced drift space, and did not increase the overall length of the matching section from the prior solution. This solution reduced the beam size in the X-plane and matched into the RFQ. The beam size in the Y-plane remained large just before the RFQ, but the strict beam requirements dictated by the RFQ matching parameters, namely the necessity that the beam be strongly convergent, and the required drift space between the final beamline component and the RFQ match point necessitates a beam that is somewhat large in at least one plane. Once 200 µA of current was included (Figure 4), the maximum beam size remained near 4.5 cm, which is larger than desired, but adequate for the purposes of this test.

The latter point was tested in a third matching solution, where a final electrostatic quadrupole pair was added near the last pair. This increased the length of the matching section by 39 cm. Furthermore, while the solution matched into the RFQ, the beam size in the X-plane increased to over 5.2 cm. Several iterations of this solution were attempted, but the results were all similar.

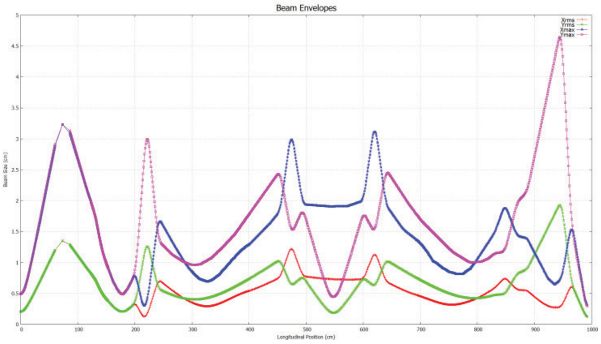

Figure 3: 3 ESQ Doublets. See Figure 2 for details.

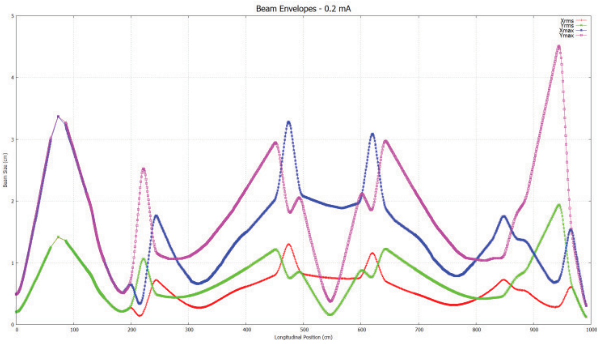

Figure 4: 3 ESQ Doublets with 0.2 mA.

## FUTURE WORK AND CONCLUSIONS

The development of the test facility LEBT is still in the early stages. Further simulations will include alternative matching solutions, including space charge contributions. Additionally, multiple charge state beams must be investigated further. Once these studies are performed, fringe field effects, higher-order dynamics, and error analysis must be performed. These studies will likely result in significant changes to the lattice. Furthermore, as the diagnostics systems are developed, more changes in the lattice can be anticipated.

These studies have provided a proof-of-principle for RISP's test facility LEBT. It should be possible to provide beam of acceptable quality for the purposes of the test facility. This beam will be achromatic, small in transverse radius, and match into the RFQ.

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