ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAL116

DEVELOPMENT AND INSTALLATION OF THE CANREB RFQ BUNCHER AT TRIUMF*

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Abstract

Pure, intense rare isotope beams at a wide range of energies are crucial to the nuclear science programs at TRIUMF. The CANREB project will deliver a high resolution spectrometer (HRS) for beam purification, and a charge breeding system consisting of a radiofrequency quadrupole (RFQ) beam cooler and buncher, an electron beam ion source (EBIS), and a Nier-type spectrometer to prepare the beam for post-acceleration. Bunching the beam prior to charge breeding will significantly enhance the efficiency of the EBIS. The RFQ buncher will accept continuous 60 keV rare isotope beams from the ARIEL or ISAC production targets and efficiently deliver low emittance bunched beams. A pulsed drift tube (PDT) will adjust the energy of the bunched beam for injection into the EBIS to match the acceptance of the post-accelerating RFQ. Ion optical simulations were carried out to inform the design of the RFQ buncher and PDT. Simulations indicate that delivery of up to 10^7 ions per bunch with high efficiency is possible. Experience with previous beam bunchers was also brought to bear in the design effort. Installation of the RFQ is under way, and tests with offline beam are expected to be performed in late 2018.

OVERVIEW

TRIUMF is in the process of building the Advanced Rare IsotopE Laboratory (ARIEL) to enable the delivery of up to three rare isotope beams simultaneously. Part of the infrastructure upgrade involves facilitating the purification and efficient post-acceleration of rare isotope beams of interest. The CANadian Rare isotope facility with Electron Beam ion source (CANREB) will include a high resolution magnetic spectrometer (HRS), a radio-frequency quadrupole (RFQ) beam cooler and buncher, a pulsed drift tube (PDT), an electron beam ion source (EBIS), and a Nier-type magnetic spectrometer. The HRS consists of a pair of 90° dipole magnets with a multipole in between to correct for higher order abberations. It has a design resolution of 20,000 to separate out the isotope of interest. The EBIS will charge breed incident beams to an A/Q of between 5 and 7, and the Nier spectrometer will select out a single charge state for post acceleration. However, to operate efficiently, the EBIS requires injection of bunched beam.

The RFQ buncher will accept rare isotope beams from either the existing ISAC facility or one of the future ARIEL target stations and efficiently deliver bunched beams of up to 10^6 ions per bunch at 100 Hz to the CANREB EBIS. A pulsed drift tube will be installed between the RFQ and EBIS to match the energy of the ≤60 keV bunched beam to the 10-14 kV EBIS bias such that the charge-bred beam matches the 2.04 keV/u acceptance of the post-accelerating RFQ in ISAC.

A cutaway view of the CANREB RFQ model is displayed in Fig. 1. The entire RFQ structure is floated to up to 60 kV, producing a decelerating electrostatic field as the beam arrives as well as a re-acceleration as the beam bunch exits the buncher. As the beam arrives, it is focused into the RFQ structure by an immersion lens. The central region is filled with helium buffer gas for beam cooling to a pressure of about 0.05 mbar, with differential pumping structures upstream and downstream to reduce the pressure in adjacent sections of the system. The RFQ electrodes are segmented to allow the application of longitudinal DC fields to guide ions through the gas-filled cooling region and settle into a potential minimum in one of the bunching regions. After a predetermined bunching time, typically around 10 ms, the potentials on the bunching segments are switched to open the trap, releasing the ions toward the EBIS.

RFQ DESIGN FEATURES

The design was informed by ion optical simulations as well as the development and commissioning of the BECOLA beam cooler and buncher [1]. The segmented RF electrode and differential pumping structures, which were demonstrated successfully in BECOLA operation, were incorporated into the CANREB design. The RF is coupled to the segmented RFQ electrodes capacitively through a set of RF backbone electrodes which run the length of the RFQ, separated from the associated segments by a 0.005" layer of Kapton. Additional DC biases are applied to individual segments, bypassing the backbone electrode. The RFQ elec-

* CANREB is funded by CFI, Nova Scotia Research and Innovation Trust (NSRIT), Manitoba Research and Innovation Fund, Saint Mary's University, University of Manitoba and TRIUMF
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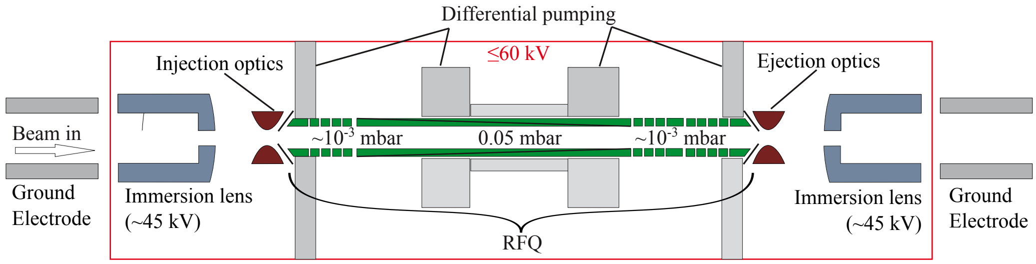

Figure 1: Sketch of CANREB RFQ.

trode design has also been demonstrated to be capable of operation with RF amplitudes well above 1 kV_{pp}, which is crucial for bunching high intensity beams.

To mitigate potential steering effects, a new mounting scheme was implemented to guarantee better alignment of the electrodes to the designed beam axis. Tight mechanical tolerances in the support structure enforce concentricity of the RFQ electrode structure and the injection and ejection optics. In addition, the aforementioned optics were designed to include segmented immersion lenses to enhance tuning the beam into and out of the buncher, as well as to make the system more tolerant of beam steering. The lens focuses off-center beams back towards the beam axis, and the segmentation allows for additional steering as needed.

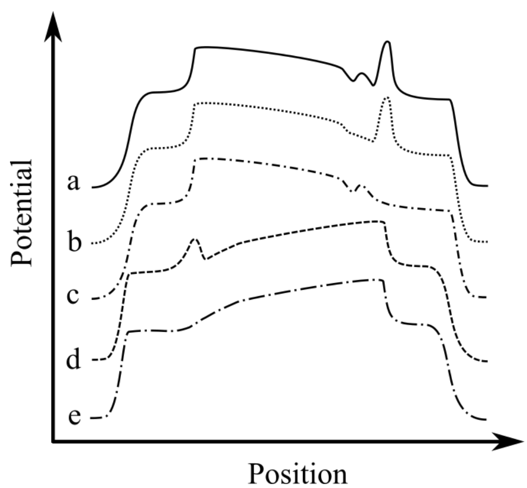

Figure 2: Sketch of on-axis DC potentials. a) Ions accumulate in the first of two potential minima on the right. b) Bunch is transferred from the 1st to the 2nd trap. c) Trap is opened allowing the bunch to exit. d) Ions accumulate in the buncher at the entrance. e) Ions are reverse extracted from the reverse extraction buncher. Note: Potentials are not to scale and are offset for clarity.

The CANREB RFQ has been designed with three possible bunching regions. A bunching region has been included in the injection stage to allow for the possibility to cool ions in the cooling section and guide them backwards so that bunches can be reverse extracted, or ejected back in the direction from whence they arrived, similar to the implementation of reverse extraction from the TITAN RFQ [2]. This feature allows the CANREB RFQ buncher to send bunched beams to a variety of experiments in ISAC requiring low energy bunched beams. In addition, for operation in forward extraction mode, an additional accumulation trap has been added to the design. Using an accumulation trap upstream of the final bunching stage allows the ions in a given bunch to cool in the buncher for the full bunching cycle time, instead of arriving continuously throughout the cycle. The implementation is similar to that demonstrated in the TITAN MRTOF RFQ system [3]. Sketches of the different potential configurations associated with bunching and ejection for both forward and reverse extraction operation are shown in Fig. 2.

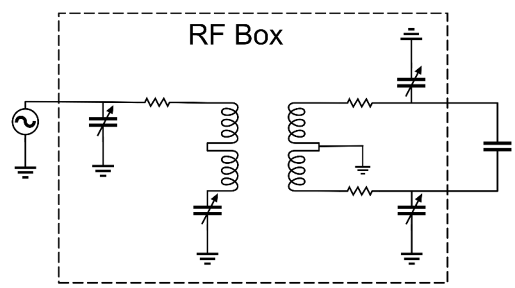

Figure 3: Schematic of RF circuit.

The RF circuit incorporates the RFQ structure as the capacitive portion of a resonant LC circuit impedance matched to the 50 Ω output impedance of the RF amplifier. Tuning capacitors have been included to allow for precise phase and amplitude matching at the pole tips. A schematic of the circuit is shown in Fig. 3. Preliminary tests demonstrate matched phases to within about 2.5%, which is within the requirements for successful operation with beam.

SIMULATIONS

Ion optical simulations [4] were performed to validate the CANREB RFQ design concept, in particular with respect to device acceptance, efficiency over a wide ion mass range, and buncher capacity. Bunching simulation results are shown in Fig. 4 for mass 30 ions with 6 MHz, 1.1 kV_{pp} RF frequency and amplitude. Particle-in-cell code was incorporated to model the effects of space charge on the ion bunch phase space. The results indicate that the required 10^6 ions/bunch are well within the device capability, and that 10^7 ions/bunch should be attainable before the 50 eV energy acceptance of the downstream bender becomes a concern.

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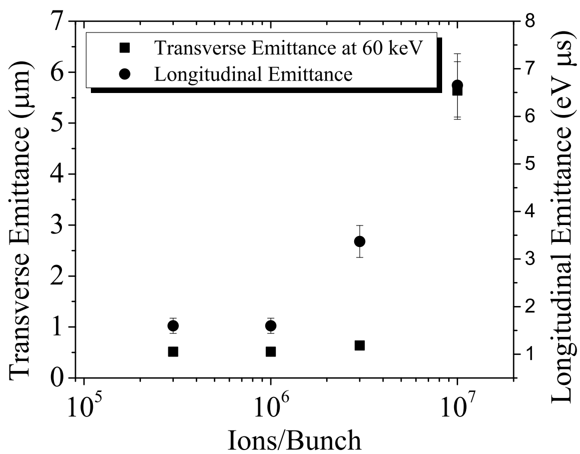

Figure 4: Simulated emittances of extracted beams. Beam energy is 60 keV.

PULSED DRIFT TUBE

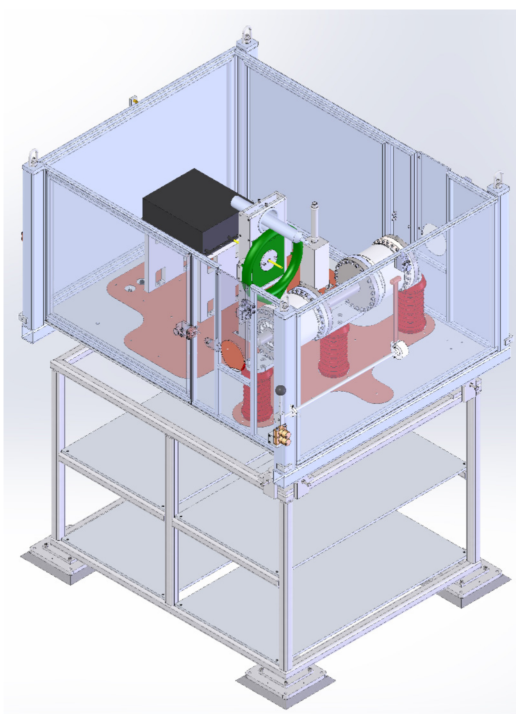
Figure 5: Design image of the CANREB pulsed drift tube with stand and high voltage safety enclosure.

A prototype pulsed drift tube structure was built and tested to determine if the tube bias could be switched from up to 54 kV to ground with minimal fall time and ringing. The tube is 70 cm in length, and is mounted to vacuum ceramic HV breaks. Switching voltages of up to 55 kV, with 90% to 10% fall times of approximately 200 ns with negligible ringing, were measured. However, the space between the high voltage safety enclosure bulkhead and the commercial switch was insufficient to maintain the full bias, especially as the switch warmed up after prolonged use at the full 100 Hz rate. To resolve these issues, the enclosure was redesigned to allow much more clearance around the switch (see Fig. 5), and a new switch was purchased with cooling channels built into the chassis.

STATUS AND OUTLOOK

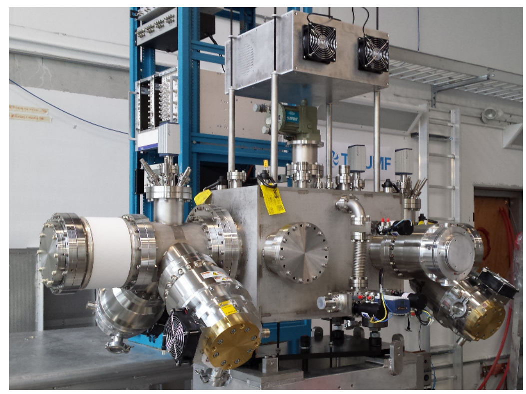
Figure 6: CANREB RFQ buncher installed in the ARIEL hall at TRIUMF.

Construction of the RFQ buncher has been completed, and it has been installed in place in the ARIEL hall at TRIUMF, as shown in Fig. 6. Preparations for testing the vacuum and gas handling systems, as well as the electrode switching in conjunction with RF circuit operation, are underway. Tests with beam from an offline ion source are scheduled to take place late in 2018.

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