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PROGRESS ON THE TRIUMF HIGH RESOLUTION MASS SEPARATOR BEAM COMMISSIONING

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Abstract

A new ISOL (Isotope Separation On Line) rare isotope beam production facility, ARIEL (Advanced Rare IsotopE Laboratory), is being commissioned to triple the availability of radioactive ion beams for the ISAC experimental facilities at TRIUMF. Part of ARIEL is the new CANREB (CANadian Rare isotope facility with Electron Beam ion source) facility which includes a charge breeding system with RFQ (Radio Frequency Quadrupole) cooler, EBIS (Electron Beam Ion Source) and Nier separator, and a high-resolution mass separator system (HRS). The HRS is designed to achieve a resolving power of 20,000 for a transmitted emittance of 3 µm with an energy spread of 0.5 eV for a beam energy up to 60 keV. The beam commissioning with stable ion beams was staged, using optical tunes developed for several mass resolving powers. The highest resolving power as per design, requires correcting the high-order aberrations using our electrostatic multipole featuring an unconventional rectangular design. This paper summarizes the multipole performance and the current status of the mass resolving power achieved with the HRS, as well as issues encountered during the commissioning runs.

INTRODUCTION

The new ARIEL beam facility [1] is designed to provide two additional rare isotope beams (RIB) to the existing ISAC (Isotope Separation and ACceleration) facility [2] experimental stations; such beams, produced using the ISOL method as in ISAC, are indeed a cocktail of many isotopes and isobars with mass smaller than the target material, and therefore they need to be purified before delivery.

The ARIEL RIB transport system [3], installed downstream of the two ARIEL target stations, enables the delivery of the two beams simultaneously, which, combined with the existing ISAC beam, is going to triple TRIUMF rare isotope beam capability. This beam transport system is an electrostatic beamline switch-yard designed for ion beams with energy up to 60 keV; the system covers a combined length in excess of 200 m, and it includes the components of the CANREB facility [4], amongst which is the high-resolution separator (HRS). The extracted beam from either target station can be transported through the HRS (or a different transport section), after the desired isotope is pre-selected via a dedicated (one per station) pre-separator with a mass resolving power of 300 [5]. The HRS is then necessary to further separate the radioactive isobars produced in the targets.

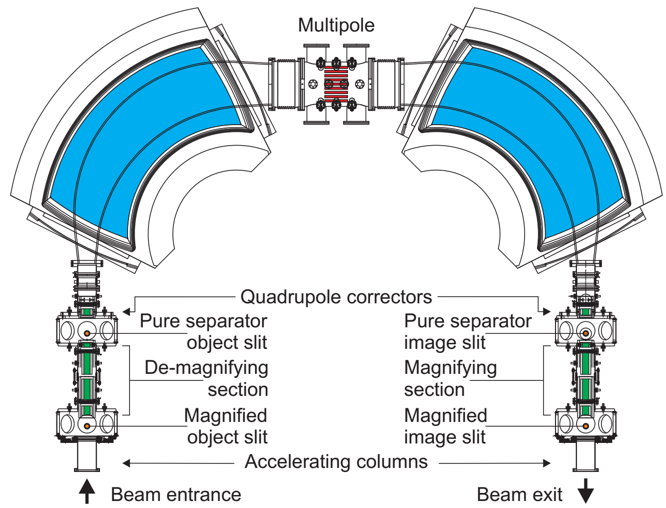

Figure 1: A beamline layout of the HRS system (top view) including the magnification and de-magnification section respectively at the entrance and exit.

The general layout of the HRS system [6], represented in Fig. 1, is similar to those of other accelerator facilities around the world [7–9] with two identical dipoles and a mutlipole corrector in between. The HRS can be tuned to different levels of resolving power, up to the designed 20,000 for a transmitted emittance of 3 µm, with an energy spread (ΔE) fraction of an electron volt. The HRS selected isotope can then be transported to the charge breeding system, or directly to the low energy or post-acceleration sections.

The HRS system is currently undergoing commissioning, with stable alkaline ion beams being extracted from a surface ion source at energies up to 60 keV [10]. Commissioning with stable ion beams has been carried out in stages, using optical tunes developed for mass resolving power ranges of 5,000, 10,000, and 20,000. Use of the electrostatic multipole is required to correct for higher-order aberrations when the product of intended resolving power and emittance exceeds 30 mm, for example with an emittance of 3 µm, for resolving power higher than 10,000.

BEAMLINE LAYOUT

The HRS optical configuration [11] (see Fig. 1) consists of two identical 90° dipole magnets with a bending radius of 1.2 m [12], an electrostatic multipole in between the

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dipoles. The system is mirror symmetric about the centre of the multipole. At entry, there is a 4-quadrupole matching section that takes the beam waist from the periodic transport and focuses it down by a factor up to 10 at the object slit of the separator. We call this the "pure separator object slit" to distinguish it from the upstream slit.

At the exit side there is the pure separator mass selection slit, and the same matching section again but reversed, as its function is to magnify the horizontal beam by the same factor as it was de-magnified at the input. The ultimate intention is to operate using the slits at the magnified locations, to reduce erosion effects and mechanical tolerance issues at the "pure separator" slits.

There are small quadrupoles (correctors) between the dipoles and the match/magnifier optics sections. These are to fine-tune the first order optics.

Both dipoles' entrance and exit edges have angles of 26° for vertical focusing and curvature of 2.2 m for second-order aberrations correction, so that in principle the multipole needs to correct only orders higher than the second.

The multipole, depicted in Fig. 2, has a novel design with 44 cylindrical pole tips of 0.5 cm radius and 20 cm length spaced 0.5 cm apart. The complex configuration of the applied voltage to the poles is simplified to an analytic function [13]. The top and bottom poles are paired together, providing 19 pairs, while the left and right poles are left as 6 individual knobs; this makes a total of 25 knobs and an electrostatic mid-plane symmetry.

The multipole is positioned with a 90° phase advance relative to the pure separator image slit; by taking emittance measurements at this location, we can calculate the required potential to be applied to pole tips in order to correct non-linearity in the beam transported through the HRS. A high-level application (HLA) has been developed for this purpose. The measured beam emittances at the location of image slit before and after the multipole correction are presented in the next section.

The matching sections with four quadrupoles can be symmetrically tuned to achieve a horizontal de-magnification/magnification up to 10 at the location of pure separator slits with respect to the relative magnified slits according to the required resolving power.

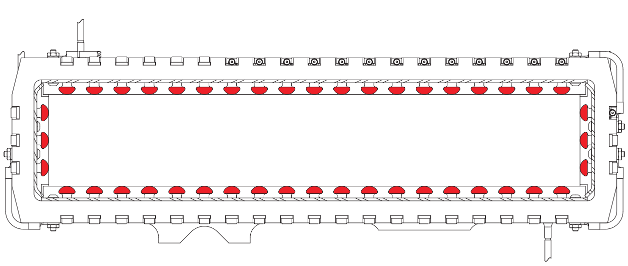

Figure 2: A transverse (xy-plane) cross-section view of the electrostatic multipole corrector of the HRS system. Each electrode (marked in red) is 200 mm in length, the inside horizontal width is 290 mm.

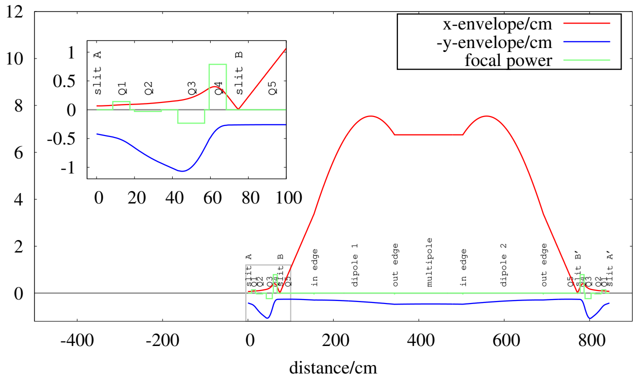

Figure 3: Calculated beam envelope (2RMS, positive for x, negative for y) for a 30 keV $^{85}Rb^{1+}$ beam transport through the HRS system with ε_{4rms} = 3 µm (H) by 6 µm (V). The inset shows the de-magnifying/matching section with magnified object slit (A) and pure separator object slit (B).

The design angular acceptance of the HRS is ±60 mrad, and the full-width slit ($2S$) for a resolving power of 24,000 is 100 µm with a given 4*RMS emittance of 3 µm and an energy spread (ΔE) of 1 eV for a 60 keV beam.

Figure 3 shows the calculated envelope through the HRS system starting from the magnified object slit to the magnified image slit using the TRANSOPTR code [14, 15]; the beam envelope is calculated for a required magnification of 9 in order to achieve a resolving power of 16,000 with a given 4*RMS emittance of 3 µm and a ΔE of 1 eV for a 30 keV beam. The mass dispersion of the pure HRS is 2.4 m, and thus a resolution of 16,000 requires a full slit size of 150 µm

The primary diagnostic devices in the HRS system are Faraday cups (FC), slits (SL), and Allison type emittance scanners (EMIT) used to measure the beam parameters in both the horizontal (x) and vertical (y) planes. Slits are used for beam phase space selection as well as beam profile measurements; horizontal and vertical slits are installed at all pure separator and magnified locations, for a total of 8 devices. The emittance scanners are installed at both the entrance and exit of the separator system, namely at the pure separator object and image slits; these devices are also capable of measuring low intensity RIB beams.

EMITTANCE MEASUREMENTS

The HRS system is commissioned with stable alkali ions extracted from the test ion source mentioned earlier in the introduction. The extracted beam from this ion source is transported through a 15 m long electrostatic beamline up to the separator entrance defined by the magnified object slits. In this work, $^{85}Rb^{1+}$ beams have been used to characterize the separator's performance with a magnification of 9 tune.

Figure 4 shows the measured phase space at the pure separator object slit location in both the horizontal and vertical planes, with a 4*RMS emittance of 3.06 µm in the horizontal plane, and 3.56 µm in the vertical plane; these values

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are consistent with the emittances measured at the exit of the source indicating no growth during transport along the beamline.

Figure 5 shows the measured phase space at the pure separator image slit location in both the horizontal and vertical planes. Here, the measured horizontal phase space shows the presence of higher-order aberrations in the beam, but there also appears to be emittance dilution.

A high level application (HLA) uses the emittance data at the pure separator image slit (left side in Fig. 5) to calculate the optimum pole tip voltages for the multipole. The left side of Fig. 6 shows the same horizontal emittance as displayed in the HLA with centroids (blue line) as well as the higher-order aberration correction (orange line) analysis. The right side of Fig. 6 shows the expected phase space at the same location after multipole correction. The result of applying the optimized pole tip voltages is shown in Fig. 7 where the measured emittance in the horizontal plane depicts a straightened and upright ellipse, demonstrating the multipole performance is in good agreement with the design expectation.

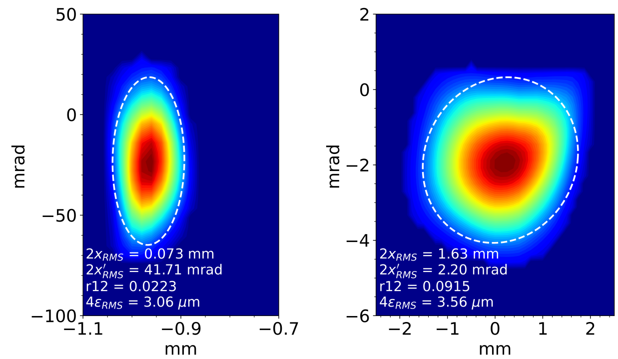

Figure 4: Measured phase space at the location of the pure separator object slit in the horizontal (x) plane (left) and in the vertical (y) plane (right).

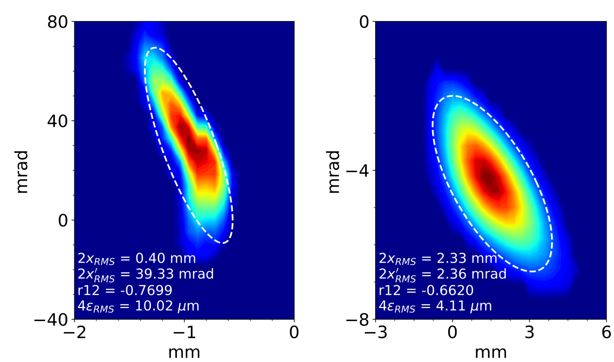

Figure 5: Measured phase space at the location of the pure separator image slit in the horizontal (x) plane (left) and in the vertical (y) plane (right).

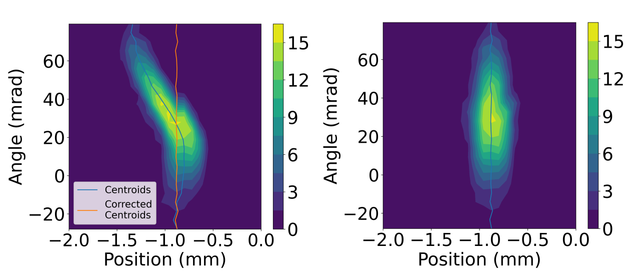

Figure 6: Analysis of measured phase space by the high-level application at the location of the pure separator image slit in the horizontal (x) plane (left), and expected phase space at the same location after multipole correction (right).

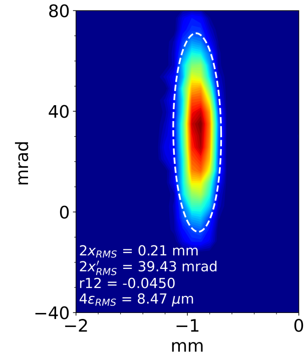

Figure 7: Measured phase space at the location of the pure separator image slit in the horizontal (x) plane with optimization of multipole corrector.

However, the 16,000 resolving power for this HRS tune is compromised because of the larger horizontal emittance compared to the one measured at the pure separator object slit; there is a growth of a factor 2.9.

Two possible causes for the emittance growth have been identified: the presence of larger energy spread (ΔE) in the transported beam through the HRS compared to its design value of 1 eV, and/or the coupling between the horizontal and vertical planes of the transported beam through the HRS. Preliminary data seems to indicate that energy spread is more likely because the emittace angular spread does not increase at all, while the beam width is about 3 times larger. The source of energy spread is currently under investigation.

SUMMARY AND OUTLOOK

The CANREB HRS system is under commissioning with a stable beam of alkali ions transported from the ARIEL test ion source. In recent work we have tuned the HRS for a high-resolving power of 16,000, and we have successfully demonstrated the performance of the novel multipole optimized to correct higher-order aberrations. However, the resolving power for this high-performance case is compromised by an unknown dilution of the horizontal emittance, which is now under investigation with two possible causes identified in energy spread, most likely, and/or coupling.

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REFERENCES

[1] "ARIEL: TRIUMF's Advanced Rare IsotopE Laboratory", in *Proc. IPAC'11*, San Sebastian, Spain, Sep. 2011, paper WEOBA01, pp. 1917–1919.

[2] R.E. Laxdal, "ISAC-I and ISAC-II at TRIUMF: achieved performance and new construction", *Proc. LINAC'02*, Gyeongju, Korea, Aug. 2002, pp. 294-298. https://accelconf.web.cern.ch/l02/PAPERS/TU302.PDF

[3] M. Marchetto *et al.*, "The ARIEL Radioactive Ion Beam Transport System", in *Proc. LINAC'16*, East Lansing, MI, USA, Sep. 2016, pp. 891–893. doi:10.18429/JACoW-LINAC2016-THPLR023

[4] F. Ames, R. Baartman, B. Barquest *et al.* "The CANREB project for charge state breeding at TRIUMF", AIP Conference Proceedings of ICIS2017 conference, Geneva, Switzerland, Oct. 2017, Vol. 2011, No. 1, p. 070010, https://pubs.aip.org/aip/acp/article/2011/1/070010/809023

[5] S. Saminathan and R. A. Baartman, "On the Ariel Pre-Separator", in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 648–651. doi:10.18429/JACoW-IPAC2017-MOPIK056

[6] Marchetto, Marco, F. Ames, R. Baartman *et al.*, "Status of the CANREB high-resolution separator at TRIUM", Nucl. Instrum. Methods Phys. Res., Sect. B 463 (2020): 227-231, https://www.sciencedirect.com/science/article/abs/pii/S0168583X19303349

[7] T. Kurtukian-Nieto, R. Baartman, B. Blank *et al.*, "SPIRAL2/DESIR high resolution mass separator", Nucl. Instrum. Methods Phys. Res., Sect. B 317 (2013): 284-289, https://www.sciencedirect.com/science/article/pii/S0168583X13008860

[8] C. N. Davids, D. Peterson, "A compact high-resolution isobar separator for the CARIBU project", Nucl. Instrum. Methods in Phys. Res., Sect. B 266, no. 19-20 (2008): 4449-4453, https://www.sciencedirect.com/science/article/pii/S0168583X08007544

[9] M. Comunian, C. Baltador, L. Bellan, M. Cavenago, A. Pisent, and E. Khabibullina, "Design of High Resolution Mass Spectrometer for SPES", in *Proc. IPAC'18*, Vancouver, Canada, Apr.-May 2018, pp. 3252–3254. doi:10.18429/JACoW-IPAC2018-THPAK021

[10] S. Saminathan, F. Ames, R. Baartman *et al.*, "Tomography reconstruction of beams extracted from an ion source", Rev. of Sci. Instrum., 90(12), p.123302, (2019), https://pubs.aip.org/aip/rsi/article/90/12/123302/1018580

[11] J. A. Maloney, R. Baartman, M. Marchetto, "New design studies for TRIUMF's ARIEL High Resolution Separator", Nucl. Instrum. and Methods Phys. Res., Sect. B 376 (2016): 135-139, https://www.sciencedirect.com/science/article/pii/S0168583X15012082

[12] M. Marchetto, "Magnetic field study for a new generation high resolution mass separator", PhD thesis (2017), University of British Columbia (UBC), https://open.library.ubc.ca/collections/ubctheses/24/items/1.0362237

[13] D. Sehayek, R. A. Baartman, C. B. Barquest, J. A. Maloney, M. Marchetto, and T. Planche, "Multipole Tuning Algorithm for the CANREB HRS at TRIUMF", in *Proc. IPAC'18*, Vancouver, Canada, Apr.-May 2018, pp. 4836–4838. doi:10.18429/JACoW-IPAC2018-THPML079

[14] R. Baartman, TRIUMF, Vancouver, Canada, Report No. TRI-BN-16-06, 2016, http://lin12.triumf.ca/text/design_notes/b2016_06/

[15] E.A. Heighway, R.M. Hutcheon, "Transoptr — A second order beam transport design code with optimization and constraints", Nucl. Instrum. and Methods Phys. Res., 187(1), pp. 89-95, 1981, https://www.sciencedirect.com/science/article/abs/pii/0029554X81904742