ENVELOPE CALCULATIONS ON THE ION BEAM INJECTION AND EXTRACTION OF CANREB EBIS

M. Pereira-Wilson, University of Waterloo, Waterloo, Canada

S. Saminathan*, R. Baartman, TRIUMF, Vancouver, Canada

Abstract

An electron beam ion source (EBIS) is being developed as a charge state breeder for the production of highly charged ions in the CANREB (CANadian Rare isotope facility with Electron Beam ion source) project at TRIUMF. The multiple tunable electrodes of the EBIS, coupled with the necessity of directing both an electron beam and an ion beam of varying charge, impose a challenging task for the optimization of the beam optics. With this in mind, beam envelope simulations have been performed to determine the acceptance of the EBIS and the emittance of the extracted ion beam. The electric field of the different EBIS electrodes were modelled using finite element analysis software and the envelope simulations were executed using beam envelope code TRANSOPTR. Preliminary results show envelope calculation as a viable candidate for tuning the injection and extraction optics of the EBIS.

INTRODUCTION

The CANREB project is being developed at TRIUMF to produce pure, highly charged, radioactive isotopes for acceleration and research in nuclear physics [1]. The main component of the CANREB project is an Electron Beam Ion Source (EBIS) that will be used to increase the charge to mass ratio of the radioactive isotope beam injected into the EBIS [2]. An EBIS uses a magnetically compressed electron beam to increase the charge of the injected ions through successive electron impact ionization. The setup of the EBIS poses a very interesting challenge for the optimization of the charge breeding process, since the same section of beam line has to transport a high intensity electron beam, and a pulsed ion beam that is singly charged on injection (1+) and multiply charged ions (n+) on extraction. With the purpose of tuning the EBIS electrode potentials, the beam simulations were performed with a beam envelope tracking code, which offers a quick and efficient tool for optimizing the beam envelope size rather than the particle tracking and particle-in-cell simulations done elsewhere [3–6]. The optimized beam envelope was then used to estimate the EBIS acceptance of the injected and extracted beams.

BEAM LINE LAYOUT

The EBIS is to be located along the ARIEL Low Energy Beam Transport (LEBT) line [7]. By the time singly charged ions reach the LEBT line, they have been mass selected to 1/20,000 resolution by the High Resolution mass Separator (HRS) [8]. The beam is then thermally cooled and bunched

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* suresh@triumf.ca

at the Radio Frequency Quadrupole (RFQ) buncher [9], and at the Pulsed Drift Tube (PDT) its kinetic energy is adjusted according to the EBIS platform potential. After the charge breeding highly charged ions are extracted out of the EBIS into the same beam line as for the injection, which is called EBIS matching section. This section composed of two einzel lenses that match the beam to the EBIS entrance. Schematic view of this section is given in Fig. 1. In order to choose the injection and extraction states of operation an electrostatic kicker is switched between the two operating states with a repetition frequency of 100 Hz. The highly charged ions will be directed into the Nier type spectrometer to select the desired ions [7].

Beam envelope simulations of the EBIS have been performed from the entrance of the matching section, i. e., kicker to the center of the EBIS trap electrode. Simulation results are presented in the following sections.

BEAM SIMULATIONS

Electron Beam Ion Source

The EBIS is composed of four distinct sections: An electron gun (egun), drift tubes, a trap electrode, a collector and a sikler lens. Schematic shown in Fig. 2 does not include the electron gun since its electrostatic properties are outside the scope of the ion beam simulations. As mentioned before, the ion beam's injection and extraction paths are the same, so once inside the EBIS the ion beam only travels inside the collector, sikler lens and drift tubes up to and including the trap. The ion beam never travels left of the trap, i. e, egun side.

To perform the ion beam simulations, the electromagnetic properties of the system must be known to a good degree of resolution. The electrostatic properties of the EBIS electrodes were obtained using OPERA TOSCA model [10] and the magneto-static properties were obtained by Heidelberg University in their development of the EBIS [2]. Plots of the along axis potentials and axial magnetic field are shown in Fig. 3, where position 0 mm corresponds to the center of the trap electrode and the colours of the electrodes along axis potential match the colour of the instruments it belong to in Fig. 2.

Electron Beam

Overlap between the ion and electron beams at the center of the EBIS trap is one of the main factor in the efficiency of charge breeding process. To provide an optimization goal for the ion beam envelope simulations, the radius and acceptance of the electron beam at the center of the EBIS trap were analytically calculated. The electron beam radius was

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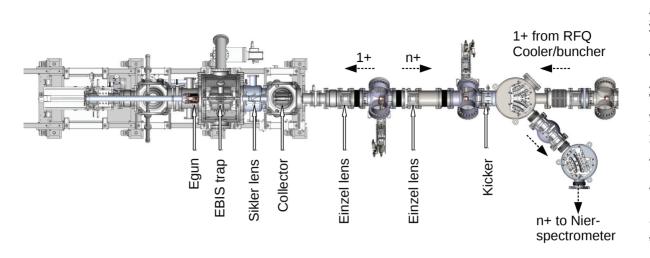**D01 Beam Optics - Lattices, Correction Schemes, Transport**

Figure 1: Top view of the EBIS and its matching section for the ion beam injection/extraction.
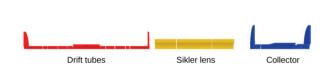

Figure 2: EBIS electrodes used in the OPERA TOSCA model (1/4 view of the full model).
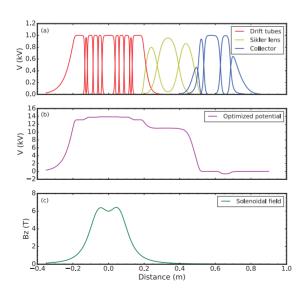

Figure 3: (a) Calculated potential along the axis of the EBIS for a given electrode biased at 1 kV, (b) Optimized potential along the axis of the EBIS according to the injection/extraction optics and (c) Calculated axial magnetic field along the axis of the EBIS and its beamline.

calculated using Herrmann's Theorem [11] and the geometrical acceptance was calculated using equation 72 from [6]. Using the input parameters shown in Table 1, the electron beam radius at the center of the EBIS trap was calculated to be 62 μm and the transverse phase-space acceptance of the electron beam to be 44 μm. The acceptance of the electron beam is the transverse phase-space in which in the ion beam should be contained and so the calculated acceptance of the EBIS is expected to have a similar value.

Ion Beam

The simulations were performed for a Cesium ion beam of 133 u as a test case. The beam envelope simulations were done with the calculated potential (see Fig. 3(a)) and the magnetic field (see Fig. 3(c)) along the axis of the EBIS and its beamline. This optimization was done using TRANSOPTR's fitting subroutine which varied the applied potential to each electrode. The outcome of the optimized potential from the envelope calculations is shown Fig. 3(b). The desired beam envelope is matched to the EBIS entrance and achieves maximum overlap with the electron beam at the EBIS trap center. The optimization of the beam envelope

Table 1: Values used for Determining Electron Beam Radius and Acceptance at the Trap

Variable name	Value
Intensity (I_e)	0.5 A
Magnetic field at trap (B)	6 T
Magnetic field at cathode (B_c)	2.1 mT
Electron energy (E)	1.6 kV
Cathode temperature (T_c)	1200 K
Radius of cathode (r_c)	3.175 mm
Trap radius at center (r_{trap})	10.1 mm
Mass of ion (m_i)	133 u

was done in such a way that the electrode potentials would remained the same between the injection and extraction.
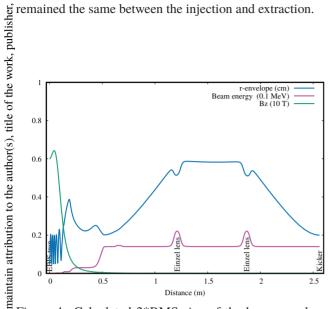

Figure 4: Calculated 2*RMS size of the beam envelope with energy and magnetic field for 14 keV Cs^{1+} ion beams injection into the EBIS.

Injection　The injection simulation begins at the entrance of the matching section (i. e. location of kicker) with a singly charged ion beam with a 4*RMS emittance of 16 μm. The result of the optimized injection simulation is shown in Fig. 4, where the entrance of the matching section is labeled kicker (on the right) and the center of the trap electrode is labeled EBIS trap. The two einzel lenses in the matching section of the beam line were optimized in order to match the beam envelope to the EBIS entrance and the EBIS electrode's potentials were optimized so the ion and electron beams radii matched at the center of the trap. The singly charged cesium beam starts with 14 keV of kinetic energy and lands at the trap center with 0.1 keV. Once the desired injection beam envelope was achieved, the beam emittance was incrementally increased until the beam envelope touched the EBIS drift tubes. The critical emittance at which this happened was determined to be the EBIS acceptance, around 40 μm. This value is consistent with the analytic calculation of the electron beam acceptance of 44 μm.

Extraction　In order to ensure that the electrode potentials that achieved the desired injection beam envelope would also work on the extracted beam, beam envelope simulations were performed on the beam leaving the EBIS. The extraction beam envelope is shown in Fig. 5. The extraction simulation begins from the trap center with the phase-space obtained from the injection simulation at the same location and the simulation end at the location of kicker. In the extraction simulation the charge state of the extracted ions was increased from Cs^{1+} to Cs^{19+}. Other effects of the charge breeding process on the ion beams transport were not included at this stage.
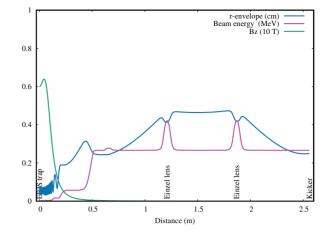

Figure 5: Calculated 2*RMS size of the beam envelope with energy and magnetic field for 266 keV Cs^{19+} ion beams extraction from the EBIS.

SUMMARY AND OUTLOOK

The simulation of the injection and extraction of ions from the CANREB EBIS was performed with beam envelope tracking code. The beam envelope was successfully optimized to achieve the desired requirements. The EBIS acceptance was determined to be around 40 μm. Future work will include the electron beam space charge potential and its effect on the ion beam transport through the EBIS. The EBIS will begin its commissioning phase soon which will allow for the benchmark of our simulation results.

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