SIMULATED PERFORMANCE OF THE CARIBU EBIS CHARGE BREEDER TRANSPORT LINE*

C. Dickerson#, S.A. Kondrashev, B. Mustapha, P.N. Ostroumov, ANL, Argonne, IL 60439, U.S.A.

Abstract

An Electron Beam Ion Source (EBIS) has been designed and is being built to charge breed ions from the CAlifornium Rare Isotope Breeder Upgrade (CARIBU) for post acceleration in the Argonne Tandem Linear Accelerator System (ATLAS). The calculated transverse acceptance of the EBIS charge breeder can approach the emittance of the injected ion beam, so beam distortion during transport could lead to incomplete injection and a decrease in the overall system efficiency. The beam quality can be maintained for simulations of the transport line using the ideal ion beam parameters. This paper reports the results of the electrostatic and ion beam transport simulations used to minimize the ion beam distortions by optimizing component designs and configurations.

INTRODUCTION

Acceleration in the Argonne Tandem Linear Accelerator System (ATLAS) requires a q/A ≥ 1/7, so +1 and +2 fission fragment beams from the CAlifornium Rare Isotope Breeder Upgrade (CARIBU) [1] require charge breeding prior to injection into ATLAS. An Electron Cyclotron Resonance (ECR) ion source is currently used to charge breed the ions, but the contamination of the accelerated beams from plasma-surface interactions within the source obscures the signal of low intensity radioactive ion beams. An Electron Beam Ion Source (EBIS) has been designed [2, 3] and is being built for the CARIBU system, and will improve the purity and intensity of the beams for post acceleration in ATLAS. The CARIBU EBIS is largely based on the Test EBIS developed at Brookhaven National Laboratory [4], and has been designed to operate with a high current, 2 A, and a low current, 0.2 A, electron gun. Ostensibly the high current gun will replicate operating conditions achieved with the Test EBIS, while the low current gun will maximize breeding efficiencies by operating in the closed-shell mode [5]. The low current electron gun was designed to produce 0.2 A to avoid possible virtual cathode formation at the low energies required to match shell closures of the injection ions (~2 keV), and the gun will employ a Ø1.6 mm cathode to maintain a high current density within the trap, ~500 A/cm2.

Ion beams from CARIBU, cooled and bunch in a Radio Frequency Quadrupole (RFQ), will have a full emittance of 3 π·mm·mrad at 50 keV for the expected mass range 80-160 amu [6]. Aside from the general desire to maintain the best possible ion beam quality during transport, the normalized emittance corresponding to mass 80 amu, 0.0035 π·mm·mrad, is only slightly smaller than the calculated EBIS acceptance under nominal operating conditions with the low current electron gun, 0.0037 π·mm·mrad. Another critical function of the transport line is to match the injected ion beam transverse emittance with the EBIS 4D phase space acceptance.

The layout in Fig. 1 indicates the various sections of the system for the offline testing configuration Transport simulations using generalized components were reported previously [7]. This paper reports the results of the electrostatic and ion beam transport simulations used to optimize the specific component designs and configurations for the transport beamlines by minimizing the transverse emittance growth of the ion beam. The ability of the offline diagnostic line to resolve individual charge states is also discussed.

SIMULATIONS

Ion beam transport simulations were performed with TRACK [8] and CST-EM Studio [9]. TRACK integrates the equations of motion for charged particles in 3D fields, but does not incorporate a numerical solver to calculate external electromagnetic fields explicitly. TRACK can use internal expressions for the fields of a number of idealized components, or can incorporate fields mapped from external solvers. TRACK allows the user to easily scale and rearrange the fields to investigate a wide variety of configurations. EM Studio, part of the CST Studio Suite, incorporates a solid modeler and numeric solver to calculate 3D static fields for arbitrary geometries. EM Studio models can be parameterized and programmatically optimized based on user-defined constraints. EM Studio was used to optimize the optical component geometries within the transport line to minimize beam distortion. Typically, the fields calculated in EM Studio were mapped, extracted, and incorporated into TRACK for particle tracking simulations. The space charge of the ion beam for the ion beam transport simulations was neglected since the maximum expected ion current from the CARIBU source will be ~1 nA.

*Work supported by the U.S. Department of Energy, Office of Nuclear Physics, under contract number DE-AC02-06CH11357.
#cdickerson@anl.gov

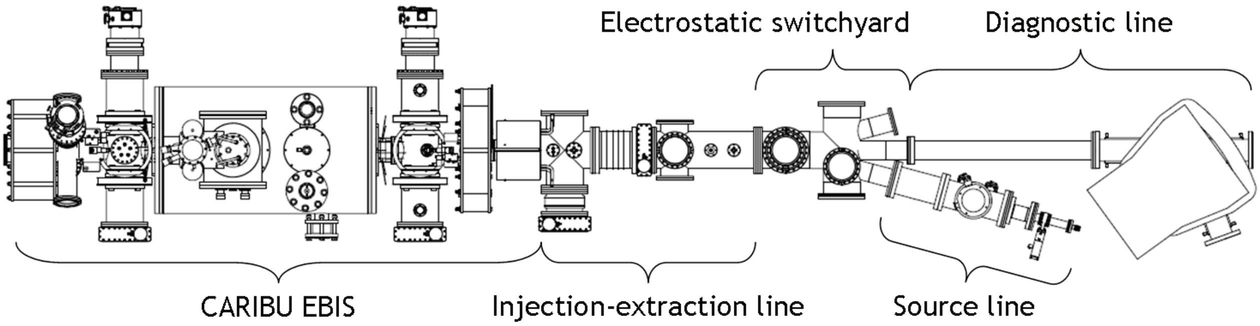

Figure 1: The layout of the EBIS charge breeder and transport lines for offline testing.

RESULTS

Injection-Extraction (I-E) Beamline

The injection-extraction (I-E) section will transport both the injected and extracted beams between the switchyard and the EBIS charge breeder. The optical elements of the I-E line – two lens assemblies, two steerers, and an acceleration tube – are shown in Fig. 2. Each lens assembly incorporates a steerer, and the extractor lens assembly uses the extraction electrode as one of its elements. The Einzel lens assembly geometries were based on the anticipated beam size and the linearity of the focusing fields. The gap and aperture combination had to produce linear focusing fields for the anticipated maximum beam diameter, ~30 mm, to minimize beam distortions. The gap between elements also had to be minimized to mitigate the influence of the grounded vacuum chamber walls on the electric field. The vacuum chambers of the I-E line are not axisymmetric, and initial simulations resulted in non-axisymmetric beams. The gaps between Einzel lens electrodes were adjusted to minimize the influence of the grounded tube, but this reduction in turn reduced the region of the linear portion of the focusing field. A lens configuration with an aperture diameter of 110 mm and gap of 20 mm was chosen for the electrodes in the I-E line to balance the range of the linear focusing fields, the influence from the grounded vacuum chambers, the strength of the lenses, and the physical size of the vacuum chamber.

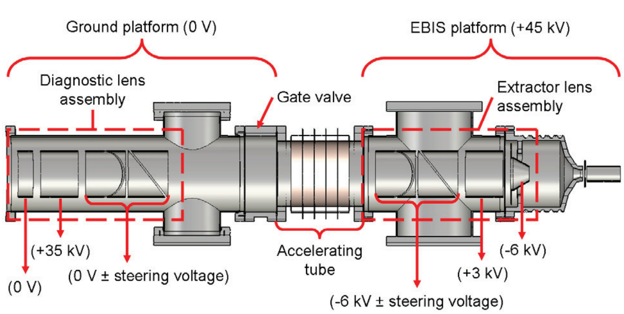

Figure 2: The electrostatic model of the I-E beamline. Nominal component voltages are shown for the injection cycle and are referenced to their respective platforms.

Three steerer configurations, shown in Fig. 3, were investigated to identify the one which maintained the best beam quality. The steerers were modelled as isolated components within a long grounded tube with the same diameter as the I-E beam pipe. A Ø20 mm 50 keV $^{133}Cs^{+1}$ beam with a full normalized emittance of 0.1 π·mm·mrad was transported through the electric field of each configuration and the emittance was monitored. Voltages were applied to the electrodes until a deflection of 13 mrad was achieved in both X and Y planes, and the results are reported in Table 1. The two sets of diagonally halved cylinders distorted the beam the least, only contributing 2% to the full normalized emittance, and were selected as the preferred steerer configuration.

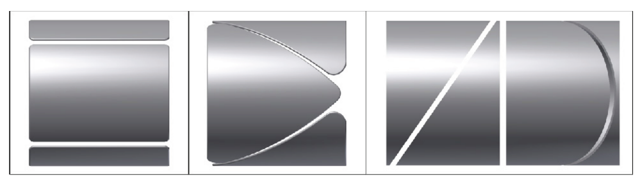

Figure 3: Side views of the three X-Y steerer configurations studied: (left) parallel quartered cylinder, (middle) diagonally quartered cylinder, and (right) two sets of diagonally halved cylinders.

Table 1: Comparison of the Emittance Growth and Strength of the Three Different Steerer Designs

Steerer configuration	**Parallel quartered**	**Diagonally quartered**	**Two sets diagonally halved**
ΔV	1000 V	1000 V	2000 V
Emittance growth	55%	10%	2%

Electrostatic Switchyard

The electrostatic switchyard will consist of a single 15° deflector to direct the injected beam from the source line to the I-E line. Nominally, the deflector will be inactive during extraction allowing the beam to travel straight from the I-E line to the diagnostic line. A schematic of the switch yard is shown in Fig. 4. The diagonally halved cylindrical configuration was chosen for the deflector because this design can maintain the beam quality better than others, as discussed with respect to the investigated steerer designs.

A focus of these simulations was to determine the deflector positioning with respect to the +15° and 0° axes so the injected beam will be deflected directly on the 0° axis. This goal was achieved by shifting the deflector midplane 0.96 cm from the intersection of the +15° and 0° axes. A spare -15° port was included in the switchyard design for the installation of additional analytical if the need arises. The -15° axis offset was investigated and was incorporated into the switchyard chamber construction to enable the on-axis deflection of the extracted beam. The axis offsets are also shown in Fig. 4.

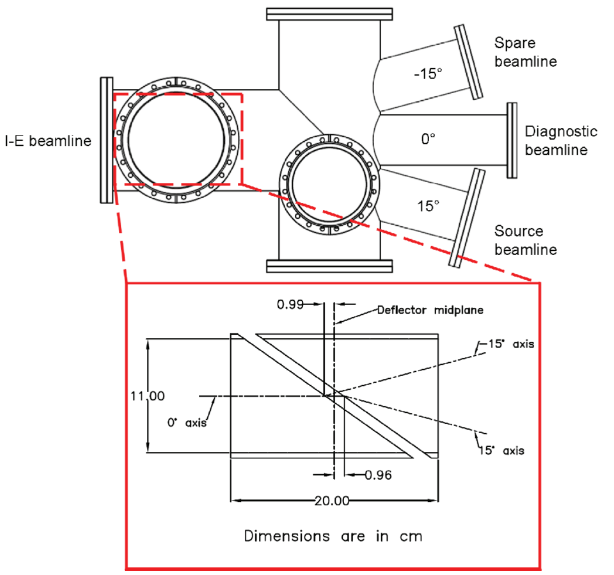

Figure 4: The electrostatic switchyard configuration and deflector positioning necessary to achieve an injected beam on the 0° beamline axis.

Offline Diagnostic Beamline

The ability of the diagnostic beamline to resolve the charge state distribution from the EBIS during the testing phase is critical to ensuring the charge breeder will meet the design specifications. The diagnostic beamline for offline testing will principally consist of a 70° analyzing magnet followed by a set of horizontal slits and a large aperture, Ø83 mm, Faraday cup. While the cup will measure the beam current, the slits should be able to isolate individual charge states if the optics permit. To simulate the resolution of the diagnostic testing beamline a multiple charge state beam was defined based on the anticipated beam parameters for extraction. The focusing required to resolve individual charge states using the 70º analyzing magnet was determined by simulating trajectories through the full I-E and diagnostic lines using TRACK. An energy spread equal to the depth of the electron beam potential well within the EBIS trap, ~370 eV for a 2 A electron beam at nominal operating conditions, was included. Fig. 5 shows the results of the individual x-x' distributions for $^{133}Cs^{+19}$, $^{133}Cs^{+20}$, and $^{133}Cs^{+21}$. The beam diameter of the $^{133}Cs^{+20}$ beam was ~10 mm and separation from the $^{133}Cs^{+19}$ and $^{133}Cs^{+21}$ beams was ~15 mm. Given this separation and the planned use of horizontal slits, accurate analysis of the individual charge state currents will be possible.

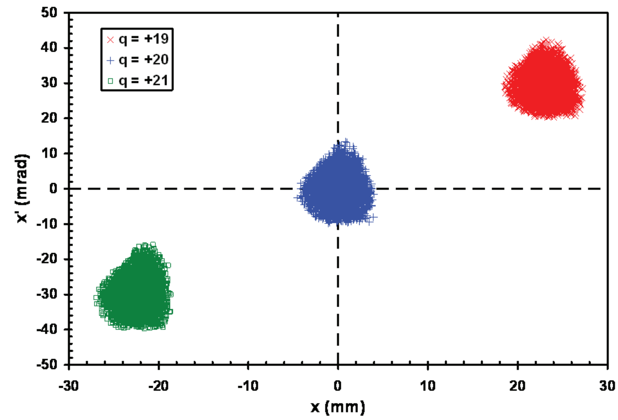

Figure 5: The transverse phase space distributions of $^{133}Cs^{+19}$, $^{133}Cs^{+20}$, and $^{133}Cs^{+21}$ at the entrance to the Faraday cup after the analyzing magnet.

Summary

An EBIS will be built to charge breed radioactive beams from CARIBU. Electrostatic and ion beam transport simulations were used to optimize the optical component designs and configurations to minimize the emittance growth of the transported beam. Designs of the Einzel lens assemblies, steerer, and electrostatic switchyard resulted. Transport simulations also showed the offline diagnostics will be able to adequately evaluate individual charge states of the extracted beam. The accuracy of these simulations will be investigated and reported as the construction of the EBIS and its ancillary systems continues.

REFERENCES

[1] G. Savard et al, Nucl. Instrum. Meth. B 266 (2008) 4086.
[2] P. Ostroumov et al, J. Instrum. 5 (2010) C07004.
[3] S. Kondrashev et al, Rev. Sci. Instrum. 83 (2012) 02A902.
[4] E. N. Beebe et al, J. Phys. Conf. Ser. 2 (2004) 164
[5] F. Wendander, J. Instrum. 5 (2010) C10004.
[6] R.C. Pardo et al, Nucl. Instrum. Meth. B 261 (2007) 965.
[7] C. A. Dickerson et al, Rev. Sci. Instrum. 83 (2012) 02A502.
[8] P. N. Ostroumov, V. Aseev, and B. Mustapha, TRACK – a Code for Beam Dynamics Simulation in Accelerators and Transport Lines with 3D Electric and Magnetic Fields, ANL, Argonne, IL, USA, v. 37 ed. (2007), see http://www.phy.anl.gov/atlas/TRACK
[9] See http://www.cst.com for CST of America, Inc., 492 Old Connecticut Path, Suite 505 Framingham, MA 01701 USA.