INITIAL SIMULATIONS OF ELECTRON AND ION BEAM OPTICS FOR THE ANL EBIS ELECTRON COLLECTOR

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Abstract

An Electron Beam Ion Source (EBIS) being developed at the Argonne National Laboratory (ANL) will be used to charge breed rare isotopes from a 1 Ci ^{252}Cf source, the Californium Rare Isotope Breeder Upgrade (CARIBU). Simulations have been performed to ensure the electron collector is properly designed to dissipate the electron beam power and provide adequate acceptance for the injected ion beam.

ANL EBIS

An electron beam ion source is being designed and will be used to charge breed rare isotopes from CARIBU for use in the Argonne Tandem Linear Accelerator System (ATLAS). The basic components of the ANL EBIS along with proposed typical operating voltages are shown in Figure 1.

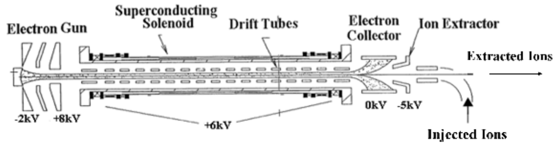

Figure 1: Generalized schematic of an EBIS.

A high breeding efficiency and short breeding times will be required to optimize the intensity of radioactive ions from CARIBU which will not exceed 10^7 ions per second. Much of the design for the ANL EBIS is based on the Test EBIS (T-EBIS) developed at the Brookhaven National Laboratory (BNL) [1]. A few key design parameters are listed in Table 1 for the ANL EBIS and the BNL T-EBIS. While the electron beam current will be largely reduced in favor of higher reliability and lower costs for the electron gun and collector systems, breeding efficiency will be comparable since the electron beam current density in the traps will be quite similar.

The electron gun, employing an IrCe cathode, from the Budker Institute of Nuclear Physics (Novosibirsk, Russia) [2], and the superconducting solenoid from Cryomagnetics (Oak Ridge, TN) are currently on order, while the design of the remainder of the system is underway. The proper design of the electron collector (EC) is critical to the efficient operation of the EBIS. Aside from its main function of dissipating the power from the electron beam, the collector is a key optical component during both the injection and extraction of ions. An electron collector for an electron lens developed by the BNL EBIS group was used as the basis for the ANL EBIS collector. The main components include the copper collector chamber, the extractor electrode, and the soft iron magnetic shielding which encircles the collector chamber.

Table 1: Comparison of design parameters for the ANL EBIS and the BNL T-EBIS.

	ANL EBIS	BNL T-EBIS
Max. electron current (A)	2	20
Cathode diameter (mm)	4	9.2
Magnetic field at the cathode surface (T)	0.18	0.18
SC solenoid magnetic field (T)	6	5
Trap length (m)	1	0.7
Current density in the trap (A/cm^2)	500	575
Max. electron energy in the trap (keV)	10	20
Max. electron energy in the collector (keV)	6	10

SIMULATIONS

Charge particle simulations were performed with a commercially available finite element software package from Field Precision LLC called TriComp [3]. The TriComp programs calculate both electrostatic and magnetostatic fields for planar or axisymmetric geometries, and can propagate model charged particles through these fields while determining a self consistent solution.

While full scale static field models were calculated for the ANL EBIS system, the electron beam simulations and, consequently, ion beam simulations were limited to a portion of the EBIS which included the collector, and the last few drift tubes nearest the collector. The reason for constraining the electron beam simulations to this area was twofold. First, the electron gun design has not yet been finalized. Second, the simulations of the electron beam avoided the very high magnetic fields within the superconducting solenoid where calculations of the very small orbits of the electron trajectories were quite cumbersome. The nearest the simulations approached the trap was at 550 mm from the trap centerline, which was roughly 200 mm from the edge of the trap.

A representative electron beam was modelled which started within a constant electric field drift tube region between the trap and the collector. The electron beam initial parameters were based on the known cathode diameter, the known magnetic fields at the gun and at the starting position in question, and the final electron energy expected based on the difference between the collector chamber potential and the cathode potential. The initial electron energies were adjusted until each had the correct final energy when incident on the collector.

Electron Beam Optics

Simulations of the electron beam within the collector are important for determining the range of electron beam energies which can be adequately controlled, the expected localized power density along the inner surfaces, and the corresponding electrode voltages which will be required during operation. The maximum power the electron beam will transfer to the collector will be about 12kW. The goal for these simulations was to have the electron beam impact the inner cylindrical surface of the collector while minimizing the amount of current incident on either the conical surface near the entrance or the vertical surface near the exit. Cooling along the cylindrical volume of the collector will be the easiest to implement, while there will be limited cooling on the conical surface and no active cooling in the vicinity of the vertical surface. Figure 2 shows electron trajectories for simulations for beam energies 3-6 keV, and a constant extractor electrode potential of 9 kV.

Figure 3 shows the power density within the collector for the electron distributions shown in Figure 2. These power densities represent the highest values anticipated for the given electron beam energies since the extractor electrode was maintained at its maximum value and mitigated electron beam expansion. The uniformity and positioning of the electron distribution along the inside of the collector is mainly influenced by the magnetic field near the entrance and within the collector and the potential applied to the extractor electrode. The shielding around the collector must be positioned so that sufficient magnetic field attenuation occurs to enhance the quick expansion of the electron beam. The extractor electrode potential will typically be set to lower values than the 9 kV shown for the simulations to allow the maximum coverage of the inner surfaces of the electron collector without impinging on the rear vertical surface.

Ion Injection and Electron Beam Acceptance

Besides a heat exchanger, the EC is an optical element which affects the interaction between the electron beam and injected ions. Properly matching the ion beam emittance to the electron beam acceptance is critical to achieving a high degree of overlapping of the two beams and, thus, efficient charge breeding. Ions from the CARIBU source will range in masses from 80 to 160, but initially a cesium surface ionization source will be used to commission the ANL EBIS, so simulations of ion injection were performed using 5 keV $^{133}\mathrm{Cs}^{+1}$ ions.

The acceptance of the electron beam near the entrance of the collector was investigated by simulating the injection of a number of ion beam distributions from a starting position within the EC where the magnetic field had been significantly shielded. The potential well created by the space charge of the electron beam is an important factor influencing the ion beam confinement, so the ions were injected into the self consistent electric field solution from the electron beam simulations. The ions were considered to be accepted into the electron beam if the radii of their trajectories at the end of the simulation were less than the cut-off radius. Figure 4 shows the phase space plots of the required injected ion distribution for the ion beam to be accepted, and Table 2 lists the corresponding beam parameters.

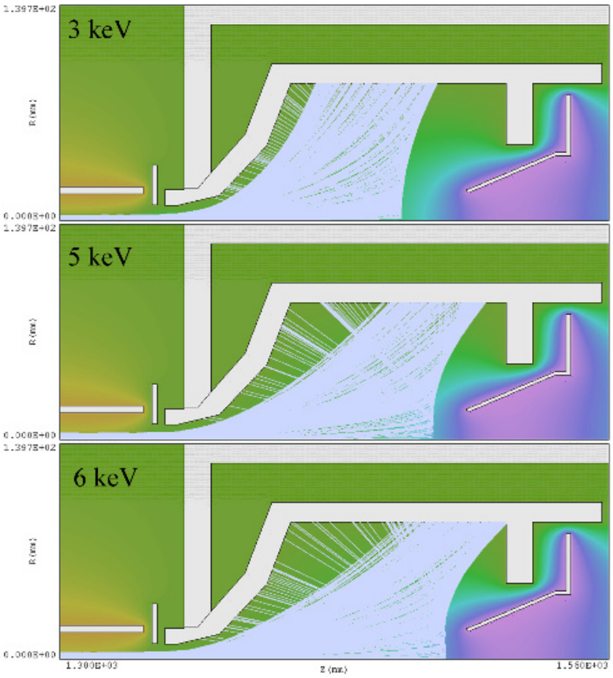

Figure 2: Electron beam distributions within the electron collector for beam energies of 3, 5, and 6, keV with a constant extractor electrode potential of 9 kV.

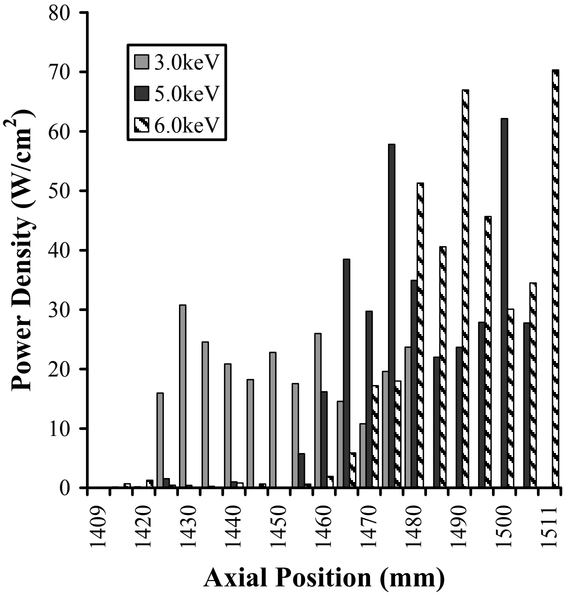

Figure 3: Power densities along the inner cylindrical surface of the collector for electron beam distributions corresponding to Figure 2.

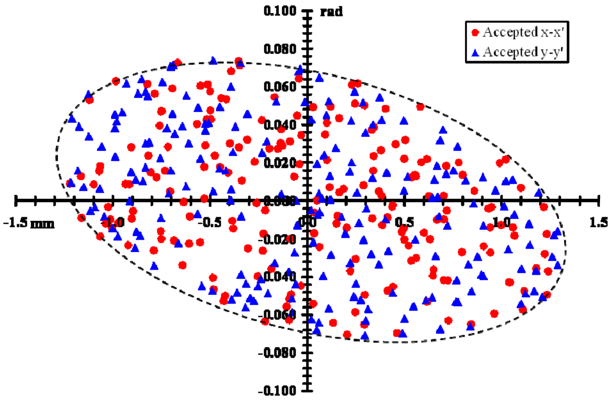

Figure 4: Required injected ion distribution.

Table 2: Beam parameters required for the injected ion beam.

Twiss Parameters			Acceptance
α	β	γ	(π-mm-mrad)
0.39	0.02	60	90

Ideally the acceptance criterion would be that for an injected ion to be considered confined within the electron beam inside the trap the maximum ion beam radius must be equal to or smaller than the electron beam radius. However, as mentioned previously simulations of the electron beam in the trap were avoided due to the high cost of calculating the very numerous and small orbits within such a high magnetic field. The injected ion beam could, therefore, also not be simulated up to the trap since the appropriate electric field solution, including the space charge of the electron beam, did not exist.

Given calculated electron beam radii of 0.64 mm at the position nearest the trap in the simulations (550 mm from the trap centerline) and 0.37 mm within the trap, an estimate of 0.5 mm at 550 mm was used as the cut-off radius for ion beam acceptance. The calculated values of the electron beam radii only took into account the magnetic fields at the various positions and not the space charge of the electron beam, so these values are slightly smaller than what is expected, and thus led to a conservative estimate for the acceptance. However, the acceptance of 90 π-mm-mrad is quite sufficient, since the expected emittance from the pre-injector RFQ cooler buncher is only 3 π-mm-mrad.

SUMMARY

For the ANL EBIS to perform efficiently the electron collector will need to be capable of adequately dissipating the power from and restricting the range of the electron beam for a variety of beam energies. It is also crucial to understand the optics within the collector to properly design the injection and extraction lines.

Simulations of electron beam distributions with a current of 2 A and energies from 3-6 keV have been used to determine the expected power density deposition within the electron collector. This information will be used to ensure the cooling system is correctly sized, and to calculate anticipated stresses in the collector during operation. Ion injection simulations were conducted to determine the acceptance of the electron beam, and the calculated acceptance of 90 π-mm-mrad will be adequate given the expected emittance from the injection line.

REFERENCES

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