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Simulation of 10 A Electron Beam Formation and Collection for a High Current EBIS*

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Abstract

Developmemt of an Electron Beam Ion Source (EBIS) for the Relativistic Heavy Ion Collider (RHIC) at BNL requires operating with a 10 A electron beam, which is approximately an order of magnitude higher current than in any existing EBIS device. A test stand is presently being designed and constructed where EBIS components will be tested. It will be reported in a separate paper at this Conference. The design of the 10 A electron gun, drift tubes and electron collector requires extensive computer simulations. Calculations have been performed at Novosibirsk and BNL using two different programs, SAM and EGUN. Results of these simulations will be presented.

I. Introduction

For injection into RHIC, an EBIS which can generate beams of U^{45+} ions with intensities of ~2×10^9 ions per pulse in a 1.5 m long ion trap, the capacity of the ion trap (number of electrons within the trap) must be 1.1×10^{12} electrons[1]. In the Electron Beam Test Stand (EBTS), a short prototype of the RHIC EBIS, the electrons will be provided by a single pass 10 A, ~10 keV, magnetically confined electron beam. Assuming a confinement time of 100 ms, and that the ions spend 50% of their time inside the electron beam, the calculated electron current density that is needed to generate U^{45+} ions is ~600 A/cm^2, meaning that for a 10 A electron beam, the electron beam diameter should be 1.5 mm. The maximum magnetic field at the center of the superconducting solenoid will be 5 T, which is more than ten times the Brillioun field.

The simulations were performed at Novosibirsk and BNL, using the SAM[2,3] and EGUN[4] code packages, respectively.

Figure 1 shows a layout of the EBTS (upper), the profile of the magnetic field and a typical beam envelope (middle), and typical axial potentials, with and without electron beam (lower).

A more detailed description of the EBTS is reported at this Conference[5].

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II. Electron Gun

Some general considerations for the electron gun design are:

i. The electron beam output should not be very sensitive to changes in gun geometry due to evaporation of cathode material, LaB_6, or in the cathode-to-anode distance.

ii. Electron beam formation in the trap, with magnetic compression by a factor of 3-10 in order to attain the required current density of ~600 A/cm^2, requires a high emission density, which leads to a shorter life-time of the cathode.

iii. The beam from a high perveance gun cannot be strongly retarded in the trap region because of virtual cathode/magnetic mirror effects. On the other hand, the trap capacity depends inversely on the electron energy.

iv. High perveance guns tend to have problems with electrical insulation.

v. Guns with concave cathodes and electrostatic focusing have a relatively narrow range over which their parameters can be changed to optimize performance for an acceptable optical emittance. For a wider range of variation, the gun should have a very strong electric field in a narrow region near the cathode as, for example, in a coaxial diode with magnetic insulation.

vi. Flexible control of electron beam parameters can be achieved if the gun is in the field of a separate, independently controlled solenoid. Varying this field, for example, changes the magnetic compression, hence the electron density in the trap.

Based on the above, the proposed electron gun uses the scheme of the coaxial diode with magnetic insulation. It is positioned in the magnetic field of a separate solenoid. The gun, see Figure 2, consists of a spherical convex cathode (LaB_6), of 10.6 mm radius x 8.3 mm diameter (transverse), a focusing electrode, and a cylindrical anode with an upstream diameter of 70 mm, and 25 mm downstream. The angle between the flat surface of the focusing electrode and the normal to the cathode is 67°, close to the Pierce angle. Figure 3 shows the results of a computer simulation for our `basic conditions': Ua = 50 kV, I = 13.64 A, and $B_{cathode}$ = 0.16 T. The optical emittance is 3.58 $\pi$ mm-mrad. This is 50% of the thermal emittance, and, based on past experience with $LaB_6$ cathodes, about 10% of the `real' emittance, which is determined by the surface roughness and temperature of the cathode. For an electron current of 1.36 A, and other parameters the same, the optical emittance is 41.52 π mm-mrad, close to the `real' emittance. Thus, over a wide range of extracted current, the emittance is dominated by the surface condition and cathode temperature.

III. Drift Tubes

The drift tube section is approximately 2 m long and consists of twelve 170 mm sections with an i.d. of 32 mm. The four central tubes define the ion trap region. The axial

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potential distributions with and without beam are shown in Figure 1(lower). The trap potential is 50% of the potential on the outer tubes (50 kV). Figure 4a shows the dependence on $B_{cathode}$ of the minimum tube potential in the trap region, and the corresponding axial beam potential, necessary to avoid virtual cathode formation. Figure 4b shows the dependence on $B_{cathode}$ of the minimum and maximum current density due to beam modulation, for the same conditions as in Figure 4a. At high fields, one sees that the density variation is small, but that the mean value of the density is also smaller.

IV. Collector

The main components used to collect the electron beam are identified in Figure 5. The magnetic field of the bucking coil keeps the beam small through the collector entrance, after which the beam rapidly expands to the wall, under the influence of its space charge. For a beam current of 13.64 A, keeping the collector at ~7 kV above the cathode potential gives a satisfactory divergence of the electron beam. A typical result, for a cold beam, is shown in Figure 5. However, test beam particles having maximum transverse velocity in the trap were also successfully transported to the collector.

V. Conclusion

The designs of the main components of the EBTS have been exhaustively simulated, and, where necessary, revised. The results presented here were from the SAM simulations, but, for the most part, were confirmed by EGUN simulations.

These simulations will continue, with extraction of the ion beam included.

VI. References

1. K. Prelec, J. Alessi, and A. Hershcovitch, European Particle Accelerator Conference - EPAC-94, London, 1994.
2. B.M. Fomel, M.A. Tiunov, and V.P. Yakolev, SAM - AN INTERACTIVE CODE FOR EVALUATION OF ELECTRON GUNS, Budker INP Report No. 96-11, 1996.
3. Y.V. Baryshev, et al, A 100 MW Electron Source with Extremely High Beam Area Compression, Nucl. Instrum. Methods-A, A 340, 241-258, 1994.
4. W.B. Herrmannsfeldt, EGUN-AN ELECTRON GUN OPTICS AND DESIGN PROGRAM, SLAC Report No. 331, 1988.
5. A. Pikin et al, BNL Electron Beam Test Stand, Proceedings of this Conference.

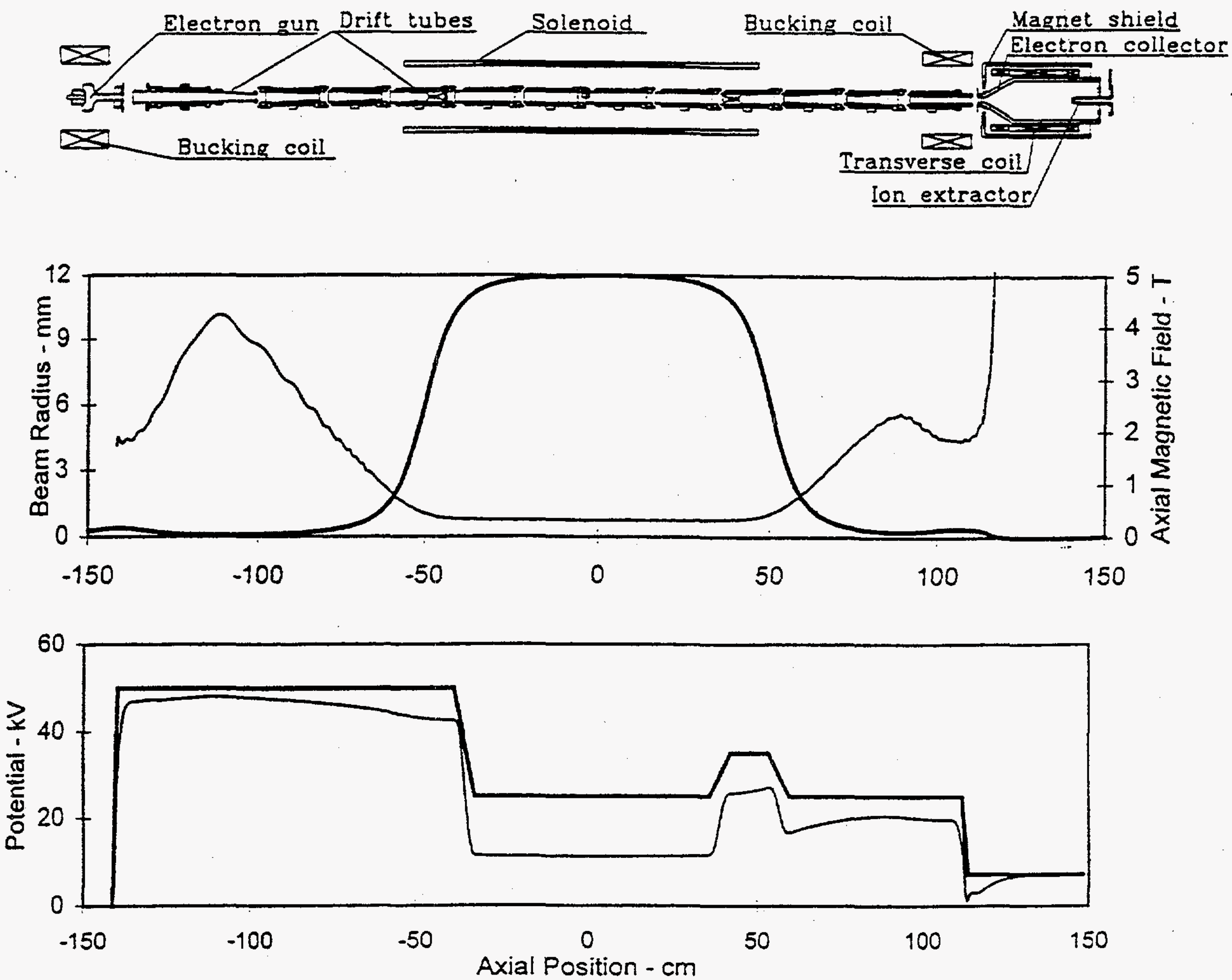

Figure 1

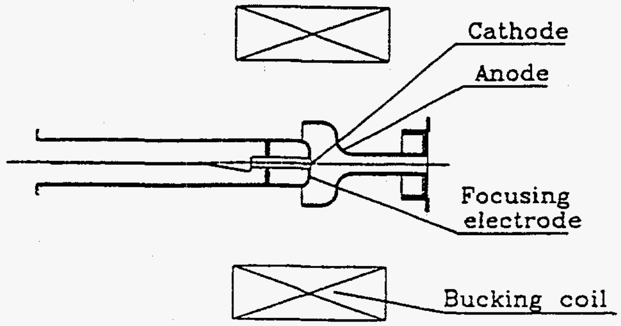

Figure 2

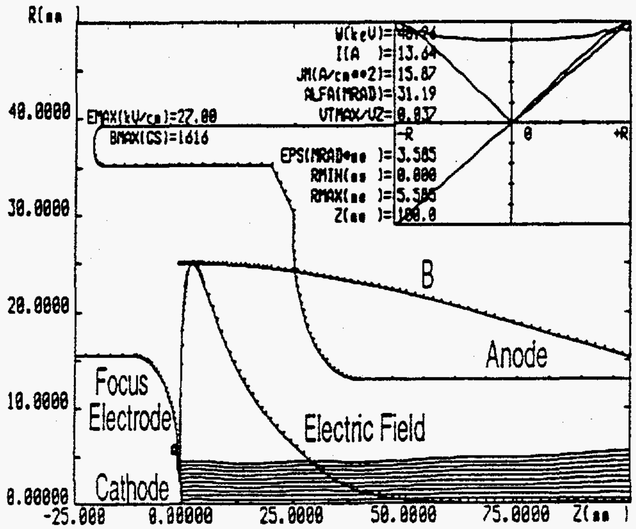

Figure 3

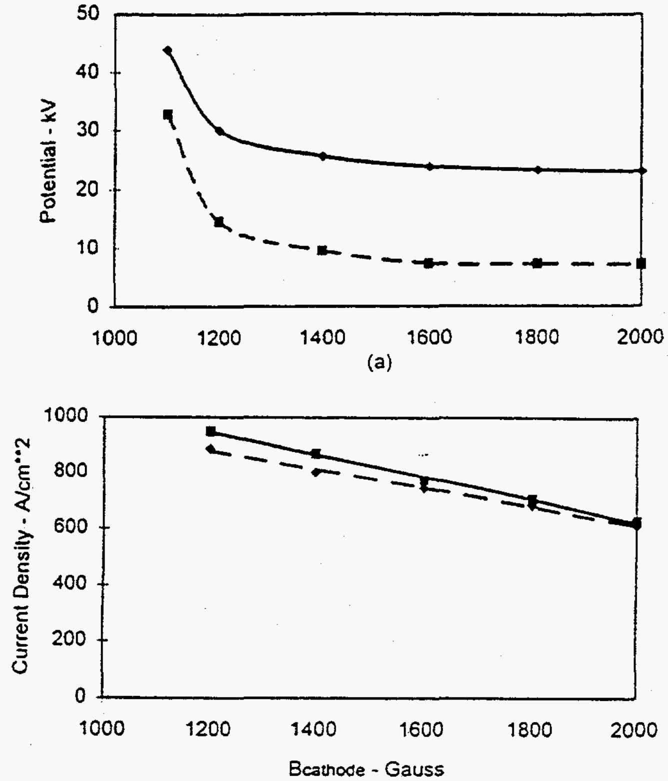

Figure 4

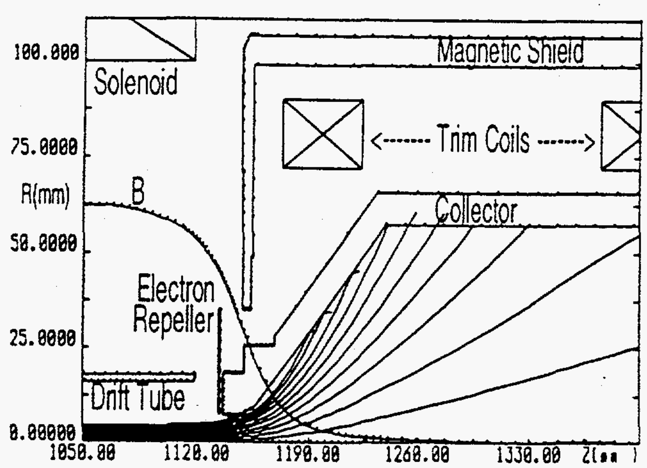

Figure 5

FIGURE CAPTIONS

Fig. 1. (Upper) - Layout of EBTS ; (Middle) - Magnetic field (thick line) and a typical electron beam envelope in EBTS; (Lower) - Axial potentials in EBTS without (thick line) and with a 13.6 A electron beam.

Fig. 2. Details of the EBTS electron gun.

Fig. 3. Simulation of 13.6 A electron beam extraction.

Fig. 4. (a) Critical drift tube potential(solid) vs $B_{cathode}$ for virtual cathode formation for 13. 6 A of electrons; (broken) Corresponding axial beam potential. (b) Maximum(solid) and minimum(broken) average beam density at the center of the EBTS trap due to beam scalloping, for the conditions of (a).

Fig. 5. Typical electron beam optics in the EBTS Collector region.