DESIGN OF AN EBIS FOR RHIC*

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Abstract

An Electron Beam Ion Source (EBIS) can be used to produce beams of high charge state heavy ions, and is an excellent choice for injection into a synchrotron, since short pulses of high intensity can be produced for single- or few-turn injection into the ring. As a result of successful experiments on a test EBIS at BNL, we are now confident that an EBIS meeting RHIC requirements can be built. This EBIS would be part of a new linac-based preinjector which would serve as a modern alternative to the existing Tandem preinjectors, offering improvements in performance and operational simplicity. The BNL test EBIS, which is a ½ trap-length prototype of the RHIC EBIS, has produced > 10^9 ions per pulse of Au^{32+}, in 10-20 microsecond pulses, and has exceeded our design goals. Performance of the test EBIS is summarized and the design of the RHIC EBIS presented.

INTRODUCTION

The present preinjector for heavy ions for AGS/RHIC uses the Tandem Van de Graaff, built around 1970. In fact, the required gold beam intensities for RHIC could only be met with a Tandem until the recent success in EBIS development at Brookhaven. An alternative to the Tandem can now be an Electron Beam Ion Source (EBIS), followed by a Radiofrequency Quadrupole (RFQ) accelerator, and a short Linac. This new preinjector offers improvements in both performance and operational simplicity. While the Tandem has proven to be reliable, quite a few systems are becoming obsolete, and would have to be replaced to maintain reliable long term operation for RHIC. The RFQ and linac are a simpler, modern, more robust technology, which will require less maintenance. Since the EBIS produces directly the high charge state desired for Booster injection, two stripping stages can be eliminated, with the accompanying intensity and energy spread variations as foils age and then break, often over a time scale of only a couple hours at highest intensities. The 860 m long transport line from Tandem to the Booster would be replaced by a line of ~ 30 m. The EBIS will inject full intensity over only 1-4 turns, as compared to 30-40 from Tandem, so injection will be much easier. Finally, the EBIS is capable of producing any ion species, while the Tandem is limited to those starting as negative ions.

The performance required for an EBIS meeting RHIC requirements is shown in Table 1. Also shown in the Table is the present performance of the prototype EBIS which is now in operation at BNL.

Table 1: EBIS parameters

Parameter	RHIC EBIS	EBTS (achieved)
e-beam current	10 A	10 A
e-beam energy	20 keV	20 keV
e-beam density	~ 575 A/cm^2	> 575 A/cm^2
Ion trap length	1.5 m	0.7 m (solenoid limit)
Trap capacity (charges)	11 x 10^{11}	5.1 x 10^{11} (10A)
Yield, charges	5.5 x 10^{11} (Au, 10A)	3.4 x 10^{11} (Au, 8 A)
Pulse length	≤ 40 μs	20 μs
Yield Au^{32+}	3.4 x 10^9 ions/pulse	> 1.5 x 10^9 ions/pulse

PERFORMANCE OF THE EBIS TEST STAND

The construction and previous results on the EBIS test stand (EBTS) have been presented [1-3]. EBTS is a ~half length version of the RHIC EBIS, capable of operating at the full 10 A electron current. With a trap half the length of the final EBIS, we have consistently exceeded our goal of half the ion yield required for RHIC. While we have demonstrated low loss operation at 10 A electron beam, we are typically operating at 7-8 A due to some trap power supply limits. Ion injection of low charge gold ions from a low energy vacuum arc ion source (LEVA) [4] and subsequent extraction of high charge state Au has been demonstrated with electron beams up to 8A. Gold spectra with dominant charge state 34+ and total ion charge of 55 nC measured on a current transformer at the EBIS exit has been obtained after a 30 ms confinement period. This corresponds to ~85% of the theoretical ion trap capacity, and exceeds our goal of 50% neutralization. Time-of-flight spectra indicate that 20% of the gold charge is concentrated in charge state 34+. The collected ion charge is proportional to the electron current and the gold charge state scales with the electron current density.

In addition to a high resolution time of flight spectrometer, we have recently installed large aperture gridded electrodes which can accept and sample the full extracted ion beam, which is then measured on a downstream Faraday cup, allowing a low resolution time-of-flight measurement of the full output current. A sample spectrum is shown in Figure 1, where one can see the gold charge states, and low mass peaks coming from ionization of background gas. This served to verify the large fraction of gold ions in the extracted ion pulse.

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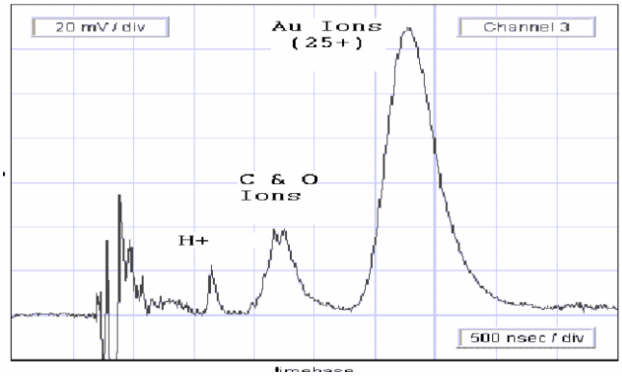

Figure 1: Course time-of-flight measurement of the total output. Ie=7A, 10 ms confinement, ~83% Au ions, peaked at 25^+. (Noise from the chopper voltage pulse is to left of the H peak).

Another recent improvement has been the addition of an extra solenoid coil between the electron gun and the EBIS trap region. This allows one to increase the magnetic field, and thus the compression of the electron beam, at the entrance to the early drift tubes, resulting in a reduction in beam loss on these electrodes from the 10^{-4} level to < 10^{-5}.

EBTS performance represents more than an order of magnitude improvement over past EBIS sources. At the same time, operation has been very reproducible and stable. Some of the key features of this EBIS are the following:

- A novel electron gun design [5]. It uses a convex LaB_6 cathode, and the resultant beam, with low rotational velocity, is less sensitive to acceleration and deceleration common in an EBIS.
- A warm bore, unshielded superconducting solenoid for the main trap region. With no cryopumping in the trap region surfaces, we are less sensitive to beam losses in the trap.
- Careful vacuum separation of the trap region from the electron gun and electron collector regions.
- Large bore (32mm) drift tubes have been used, compared to the 3-9mm tubes typical for an EBIS. This helps with pumping in the warm bore and reduces loading (desorption) effects. It also reduces the requirements on alignment, and with the electron beam far from drift tube gaps lessens RF coupling.
- The use of auxiliary (warm) solenoids, one near the electron gun and one in the transition region at the entrance of the electron collector. This allows the gun and collector, which are both sources of vacuum degradation, to be located far from the ionization region, thereby accommodating differential pumping stages. This also allows additional control of the electron beam launching, compression, and collection. In addition EBTS makes use of many transverse magnet coils for steering corrections from the electron gun to the collector.
- Since the desired charge state can be reached in 10's of milliseconds, while the time between pulses is 100's of milliseconds, the electron beam is pulsed to reduce the average power on the electron collector.
- Very versatile controls allow one to easily apply a time dependent potential distribution to the ion trap [6]. The controller coordinates the application of all time dependent voltages and timing references associated with the ion source, with a time resolution of 1 µs. At present, to simplify the user interface, the software limits the distribution to 10 EBIS subcycles or "plateaus" and 10 ramps between the plateaus. The analog functions are used to control drift tube power supplies, ramping and pulsing of the electron gun voltages, and ramping of the electron gun solenoidal field.

DESIGN OF AN EBIS FOR RHIC

Parameters for the RHIC EBIS are the following:

Output (single charge state): 1.1 x 10^{11} charges
Ion output (Au^{32+}): 3.4 x 10^9 particles/pulse
Pulse width: 10 - 40 µS
Max rep rate: 10 Hz
Beam current (single charge state): 1.7-0.42 mA
Output energy: 8.5 keV/amu
Output emittance: 0.35 π mm mrad, norm, 90%

Our experience so far in the operation of the EBTS has confirmed the validity of our approach to the design of the RHIC EBIS. The primary difference in the RHIC EBIS is the doubling of the trap length to double the ion output. Other new features we plan to incorporate into the final EBIS will be made in order to make the final EBIS more robust. A schematic of the RHIC EBIS is shown in Fig. 2. Presented below is our present concept for several key EBIS components.

Superconducting Solenoid

In order to increase the trap region length from 71 cm to 150 cm, the solenoid length will be increased from 100 cm to 200 cm. The field will remain at 5 T, but the bore diameter will be increased from 155 mm to 204 mm, in order to facilitate pumping in the longer trap region.

Electron Gun

The existing electron gun can generate an electron current of 10 A for 1000 hours, with an emission density of 13.5 A/cm^2 for 10 A electron beam. While the existing unit meets the RHIC EBIS requirements, to have a more comfortable safety factor and a reserve for a possible future increase of the ion beam intensity, it would be advantageous to have an electron gun which is capable of generating an electron beam with a current of ~15 A. To be able to extract an electron current in excess of 10A while at the same time increasing the lifetime of the gun, we plan to test a cathode unit based on IrCe rather than the present LaB_6. Published results of tests of IrCe cathodes show that even for an emission density as high as 30 A/cm^2 the lifetime is several thousands hours – much longer than we now have. In collaboration with the

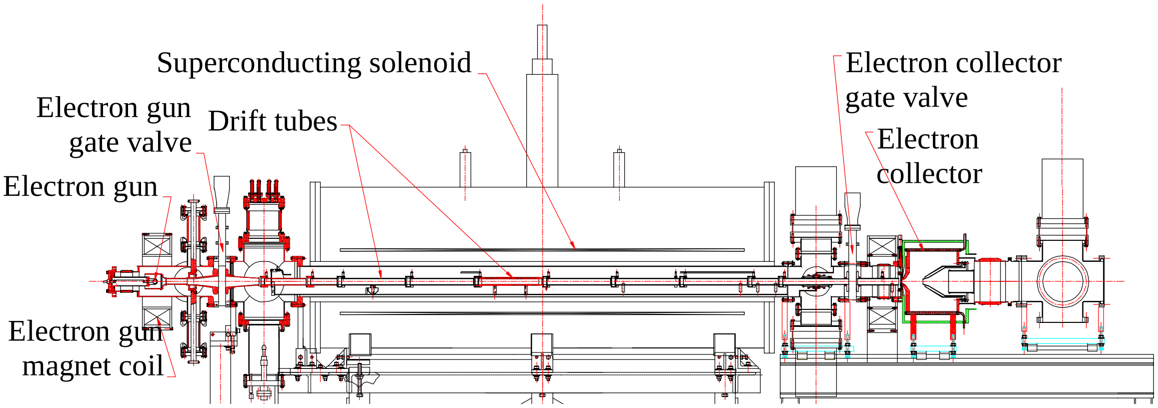

Figure 2: Schematic of the RHIC EBIS

Budker Institute of Nuclear Physics (BINP), a test of such a cathode on EBTS is planned for the near future.

Electron Collector

The main improvement in the new electron collector (EC) for the RHIC EBIS is an increase in its capacity to dissipate power, compared with the existing EC on the EBTS. The new EC will be designed to dissipate a power of 230 kW, higher than our expected load of 100 kW. To reduce the maximum power density on the surface-water interface, the longitudinal distribution of the electron beam on this surface will be made more homogeneous than in the existing EC by optimizing the shape of the magnetic field. The total area of the cylindrical water-cooled surface of the EC will also be increased; with the new collector having an inner diameter of 30 cm and a length of 24 cm. Unlike in the EBTS, the outer surface of the new EC will be exposed to atmosphere. This concept allows us to practically eliminate any probability of water leaks into the vacuum volume, because no water-cooling tubes will be in the vacuum.

Vacuum

Ion confinement times as long as 100 ms may have to be used to reach some charge states of interest. The background pressure in the trap region should be low enough that one does not produce a significant number of ions from the background gas. One can tolerate a residual gas pressure $P=1\text{x}10^{-9}$ Torr, since one then estimates that less than 20% of accumulated ions in a trap will be background gas ions. The pressure in the regions with high outgassing rate (electron gun and electron collector) can be higher than in the ionization region, provided there is efficient vacuum separation between the sections. Unlike in EBTS, the central region containing the ion trap will be preserved from venting to atmosphere during maintenance or upgrade operations with electron gun and electron collector by separating it from these regions with gate valves. In addition, there will beincreased vacuum conductivity between the middle part of the central chamber and the ends where pumps are located, due to the increase in diameter of the central chamber from our present 4” to 6”. The use of non-evaporable getters (NEG) in the region of the ion trap is also being considered.

Seeding the EBIS Trap

The primary means of seeding the trap of the RHIC EBIS will be injection and trapping of singly charged ions from an external ion source. This technique has been used very successfully on other EBISs, as well as on EBTS, and allows one to produce a very narrow charge state distribution. The requirements of the external source are relatively modest, needing currents of only about 100 µA.

CONCLUSION

The RHIC EBIS design will be very similar to the present EBTS operating at BNL. No significant improvement in performance is required, other than the straightforward scaling of ion output with an increase in trap length. Beyond this, changes to the EBTS design, which was a device built to demonstrate feasibility, will make the RHIC EBIS an “operational” device, i.e. simplier to maintain, and more reliable due to increased engineering margins on components.

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