AN EBIS-BASED HEAVY ION INJECTOR FOR THE AGS*

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Abstract

An electron beam ion source (EBIS), followed by a heavy ion RFQ and superconducting linac, can be considered as a heavy ion injector for high energy accelerators, such as the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. A test EBIS, on long term loan from Sandia National Laboratory, is presently being commissioned at BNL. Experiments on this source will be used in evaluating the parameters for an EBIS-based RHIC injector. Some results of this commissioning, as well as the conceptual designs of the RFQ and linac, are presented.

Introduction

RHIC is scheduled to be completed in 1998. Initially, the ions it accelerates will be produced in the Tandem Van de Graaff facility. However, alternative heavy ion sources, which will provide the intensity and range of ion species necessary for the full potential of RHIC to be realized, are being investigated.

Prelec *et al.*[1] have recently discussed the criteria governing the choice of key components for the proposed alternative RHIC preinjector. They concluded that an EBIS provided the best promise to meet a key requirement for a new ion source for RHIC, namely, the ability to produce a wide range of ion species of sufficient intensity. They also suggested a heavy ion RFQ for the first stage of acceleration, followed by a linac consisting of an array of independently phased superconducting coaxial $\lambda/4$ resonator cavities. The technologies involved in both of these devices are now available in industry, and they have been used under conditions similar to those proposed here. Hence we expect no problems with them in this application.

Figure 1 is a block diagram of the acceleration stages for the proposed EBIS-based injector.

EBIS

EBIS-based injectors are well suited for synchrotrons. EBISs deliver highly charged ions of virtually any species which are injected into the ion trap EBIS either as neutral gas or as low-charged ions. Particularly important is that the extracted ions can be delivered in very short (<50 μs) pulses with total charge

$$C=1.05e13\cdot I\cdot L/\sqrt{E} \quad \text{(fundamental charges)} \quad (1)$$

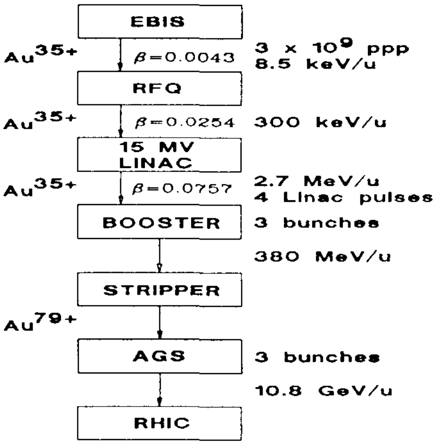

Fig. 1. The acceleration stages of the proposed EBIS-based RHIC injection.

where L is the length of the trap in meters, I is the electron beam current in amperes, and E is the electron beam energy in electron volts. Thus, it would be possible to empty the proposed EBIS in the 10 μs single-turn filling time of the Booster, which makes injection/capture very efficient. (The effect of the energy spread of a few hundred volts associated with fast emptying will be negligible since the final beam energy out of the EBIS will be 50 keV.)

The evolution of charge states depends on the electron beam energy E and the product of the electron beam density and the ion confinement time, so that the charge state is easily optimized by variation of these parameters.

Starting with his estimate of $3\text{x}10^9$ Au^{35+} ions per pulse of source output necessary to yield $1\text{x}10^9$ ions per bunch in the 57 RHIC bunches, Prelec[1] has worked out the main operating parameters of the source, based on the experience of existing EBISs. These parameters are summarized in Table 1. The 10 A electron beam current is much higher than existing EBISs produce (≤ 0.5 A). However, present stripping capabilities at injection reduce the requirement on the ion charge state, thus allowing a relaxation of other parameters which have made EBISs technically difficult.

Since SuperEBIS (the moniker given to it at Sandia) arrived at Brookhaven, the following have been accomplished:

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Missing parts, including drift tube holders, the electron gun, and the test stand, were constructed and installed.

A micromevva ion source[2] was installed and operated. 100 μs x 1 kV x 1 μA beam pulses of Ti, Ta, and U were propagated through three 3 mm slits to the collector region of EBIS (the slits are part of the TOF spectrometer[3] which was also successfully operated).

Table 1
Parameters for the proposed EBIS for RHIC

Electron beam current	10 A
Electron voltage(gun)	20 kV
(ion trap)	10 kV
Trap length	1.5 m
Trap capacity(pos. charges)	1.6 x 10^{12}
Yield, positive charges	5.25 x 10^{11}
Yield, Au^{35+} , design value	3 x 10^9
Yield, Pb^{53+} , design value	2 x 10^9

Improvements in the TOF pulsing system and detector amplifiers now allow pulse sampling down to 50 ns, resulting in well resolved injected ion spectra measured with a microchannel plate detector inserted just before the electron gun.

To speed up commissioning, a d.c. ion source which produces beams of Na, Cs, and Th, has been installed. Beams can be extracted with up to 15 kV, and then decelerated to the trap potential, presently limited to ~1 kV. Modestly operated to yield 1 μA of Na^+, verified by TOF data, the source operated for 100 hours at up to 50 Hz (~1 Hz for mevva).

Up to 5 kV x 40 mA electron beams have been propagated through the trap with >99% efficiency, indicating that the gun, solenoid, and collector are operating correctly.

Extraction of injected metal ions has not yet been observed. However, we have verified proper EBIS operation by observing TOF spectra of extracted ions of the residual gases in the ionization region. The ions H^+, He^{2+}, and H^+ were well resolved by the spectrometer. Total extracted ion charge increased linearly for confinement times up to at least 100 ms. This also showed that a known internal helium leak was not severe, and presumably would not preclude the capture and subsequent extraction of externally injected ions. The difficulty in observing such ions was due to the lack of adequate timing and voltage control of the drift tubes and ion transport optics in our present EBIS configuration, which has been remedied.

RFQ and Linac

Although it would be convenient for us to design both systems for the 201.25 MHz frequency of the present 200 MeV Linac for H^- ions at BNL, other considerations preclude this. The focusing strength of an RFQ is related to its phase advance/focusing period, the optimum value of which is ~60°. For the range of q/m we are dealing with, the frequency at which optimum phase advance occurs is ~80 MHz. On the other hand, a high frequency is necessary for the linac if the cavities are to have reasonable dimensions comparable to, say, the cavities in the ATLAS Positive-Ion Injector Linac at Argonne[4], since the starting β is 0.0254 (see Fig. 1), compared with 0.009 in the ATLAS.

Based on the above discussion, we have made our preliminary designs of the RFQ and linac using 80 and 160 MHz, respectively. With this frequency doubling, beam will occupy every other cycle of the linac.

RFQ

For Au^{35+} ions, the EBIS must produce 3x10^9 ppp of 10 μs width (for single turn injection in the Booster), which is equivalent to an instantaneous current of 1.7 mA. Table 2 summarizes the main parameters of a PARMTEQ simulation of an RFQ meeting these requirements. Figure 2 shows energy, phase and horizontal widths versus cell number.

Table 2
Parameters of an EBIS-based Injector RFQ for RHIC

Type	4 -Rod	
Frequency	80.0	MHz
Aperture radius	0.5	cm
Voltage	69.57	kV
E(Surface)	13.91	MV/m
Acceptance	0.13	π cm-mrad
Beam current	1.7	mA
Emittance(N)	0.0350	π cm-mrad
Duty Factor-Beam Pulse	0.01	%
-RF	0.0727	%
Repetition rate	10.0	Hz
Length	296.0	cm
Number of cells	176	
Transmission	97	%

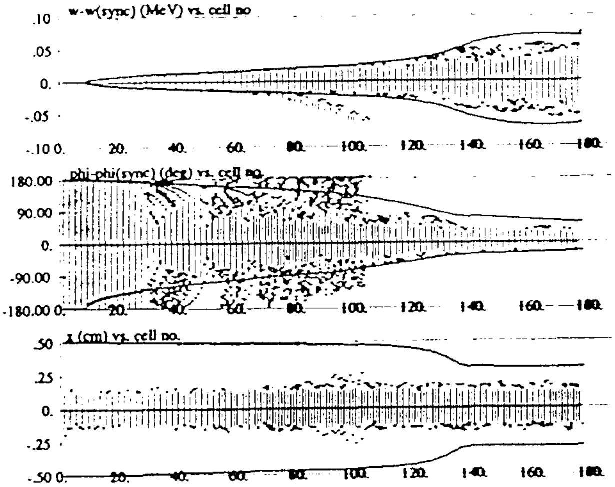

Fig. 2. $\Delta E, \Delta\Phi$, and horizontal widths vs. cell number.

Linac

We were very mindful of the successful experience of the ATLAS project at Argonne National Laboratory[5] with constructing and operating an independently phased superconducting resonant cavity linac. The key features of this type of linac are: one gets maximum use of the available voltage from all the cavities for essentially any mass ion, and every cavity can be operated at its full potential. These provide the highest energy beam for injection into the synchrotron which is always important for overcoming losses due to stripping and space charge. For now, we have chosen this approach for further study.

We also believe that since we shall be operating at a very low duty cycle (see Table 1), very high field gradients should be achievable. Since the average power dissipated by the cryogenic cooling system would be low for any gradient we would operate near the maximum limit of the structure. Furthermore, the structures themselves would be optimized in favor of low peak magnetic field as opposed to high shunt impedance as is typically done for CW linacs.

For example, assuming an operating gradient of 10 MV/m, which is 1.7 - 3 times the gradient at which the cavities in the ATLAS injector linac are driven[4], then eight cavities, of the same axial dimensions as their type T1, T2, and T3 cavities, are needed to accelerate gold 35+ ions from 300 keV/amu to 2.7 MeV/amu (see Fig. 3).

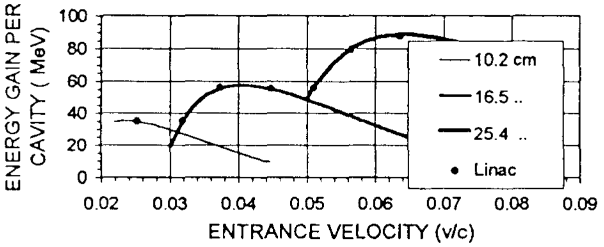

Fig. 3. Energy gain for Au^{35+} ions vs. entrance β for type T1, T2, and T3 ATLAS resonators operating at 160 MHz. The cavities have 4 gaps and are 10.2, 16.5, and 15.4 cm long, respectively, in the beam direction.

As is the case with ATLAS, superconducting solenoids between the cavities will provide transverse focusing. In Fig. 4 we show the output of a TRACE3D run[6]. The solenoids are identical - 5.5 T and an effective length of 30 cm.

Experiments at the AGS Booster have shown losses while the heavy ion beam is coasting in the machine during the accumulation stage of the acceleration cycle[7]. The loss can be significantly reduced by injecting into the Booster at higher energy., which can be done, either by extracting a higher charge state beam from the EBIS, or by raising the output energy of the linac by adding more cavities. The latter approach is preferred since, to first approximation, the output of an EBIS is inversely proportional to charge state.

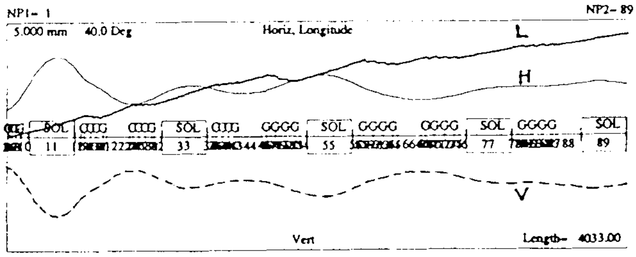

Fig. 4. Beam envelopes with solenoids in alternating gaps. The solution was not optimized for motion in the longitudinal plane.

Conclusion

We believe that our inability the extract metal ions from the EBIS thus far was due to inadequate control over the timing and voltage control of components during injection and extraction. More sophisticated control systems have been built and experiments are about to resume.

Since the RFQ and Linac are similar to devices which have demonstrated long-term operational reliability, we do not anticipate any major problems with these choices for this application.

A significant benefit of the EBIS approach is the inefficiencies of multi-turn injection are avoided since the Booster will be injected in a single turn.

We emphasize again that the results presented here are **preliminary**. The final design parameters will be set only after a more thorough review of the physics, engineering, and funding issues involved.

References

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