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# BEAM COMMISSIONING RESULTS FOR THE RFQ AND MEBT OF THE EBIS BASED PREINJECTOR FOR RHIC*

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*Abstract*

The EBIS based preinjector for both the Relativistic Heavy Ion Collider (RHIC) and NASA Space Radiation Laboratory (NSRL) is now being commissioned at Brookhaven National Laboratory (BNL). In 2008, the RFQ for the project was delivered and commissioned using Test EBIS, which was built to demonstrate the high current EBIS's performance. A dedicated beamline after the RFQ was assembled to confirm the RFQ's performance, and the beam energy was measured by a bending dipole magnet. In November 2009, the RFQ was moved to the final location and the vanes were realigned. The beam commissioning with the RHIC-EBIS was started again during March 2010.

The RFQ accelerates ions from 17 keV/u to 300 keV/u and operates at 100.625 MHz. It is followed by a short Medium Energy Beam Transport (MEBT), which consists of four quadrupoles and one buncher cavity. Some temporary diagnostics for this commissioning include an emittance probe, TOF system, fast Faraday cup, and beam current measurement units. As of September 2010, the RFQ and the MEBT show expected performance with $He^{+}$, $Au^{32+}$ and $Fe^{20+}$ beams. Further commissioning for higher intensity beams is in progress.

## INTRODUCTION

In BNL, a modern RF linac based preinjector for the RHIC-AGS complex had been desired for long time. To replace the matured tandem Van de Graaff electro-static accelerators with modern linacs, a new high current highly charge state heavy ion source had to be developed. Once the required performance was demonstrated, the RHIC EBIS project [1] was started. DOE's CD0 approval (approval of mission need) was given in August, 2004.

One of the advantages of the EBIS is its great flexibility. The EBIS can provide a wide range of species from Helium to Uranium with various charge states. The beam current and the beam pulse width also can be adjusted to match the injection requirements of the following Booster synchrotron ring. Typically the pulse width changes from 4 μs to a few tens μs and the beam current reaches a several mA.

The linac system must cover all the range of the species with different charge states. For the beam current requirement, a beam of the desired charge state is always supplied with neighboring charge state beams, and the RFQ must accommodate the enhanced space charge force caused by the unwanted charge state ions. The design parameters of the RFQ are listed in Table 1. The accelerated beam by the RFQ is matched to an IH structure drift tube linac [2] by the MEBT which has a four gap spiral structure buncher cavity and two high gradient doublet quadrupole lenses. Most of the impurities in the beam are defocused in this section. In this report, the preliminary results of the beam tests are described.

Table 1: Design parameters of the RFQ

| | |
|---|---|
| Frequency | 100.625 MHz |
| Input energy | 17 keV/u |
| Output energy | 300 keV/u |
| Mass to charge ratio | 6.25 |
| Beam current | 10 mA |
| Output trans. emit. norm. 90% | 0.38 π mm mrad |
| Output long. emittance 90% | 220 deg keV/u |
| Transmission | 98% |
| Electrode voltage | 70 kV |
| RFQ length | 3.1 m |
| Cell number | 189 |

## RFQ

The RFQ was designed and fabricated in IAP, Frankfurt and was delivered to BNL in October 2008.

### *Initial test*

After low power RF measurement, the RFQ was commissioned using high power up to 150 kW and was connected to the Test EBIS which is a half length scaled source of the RHIC EBIS. The first beam test results were reported in PAC09 [3]. Then a simple beam line consisting of quads and a 45 degree 1 T dipole were assembled to analyze the beams. In these tests, $Cu^{10+}$, $He^{2+}$, $He^{+}$ and $Ne^{5+}$ were used. The beam energy was confirmed as 300 keV/u and could be varied within ±2.5 keV/u depending on the vane voltage. The momentum spread was measured as ±2 % based on the beam size after the bend. Most of the measured results seemed satisfactory, however an unexpected vertical kick of the extracted beam was observed. For example, when we accelerated $He^{+}$ beam (q/m = 1/4), the vane voltage

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reached the nominal value at about 50 kW of RF power. As one raised the rf power up to 140 kW, rather than measuring the expected constant current at the end of the beamline, it oscillated in intensity over five cycles during the RF power scan. It was found that the accelerated beam had a small angle at the exit which changed depending on the vane voltage. The beam current reduction could be completely compensated by a steering magnet just after the RFQ. Although this could have been caused by a misalignment of the injected beam, as described below, this seems to have been caused instead by a misalignment of the vanes.

### *Re-alignment of vanes*

The RFQ was moved to its final location in November 2009. At that time, we found that the vanes at the injection side were mispositioned. All the low power cavity properties were checked again but were not changed from our initial measurements. We concluded that the initial beam test were probably done with these mis-aligned vanes, although it was not clear when the vanes were shifted. (Perhaps stresses accumulated during the machining of the vanes were released by vibrations during shipping from Frankfurt to New York).

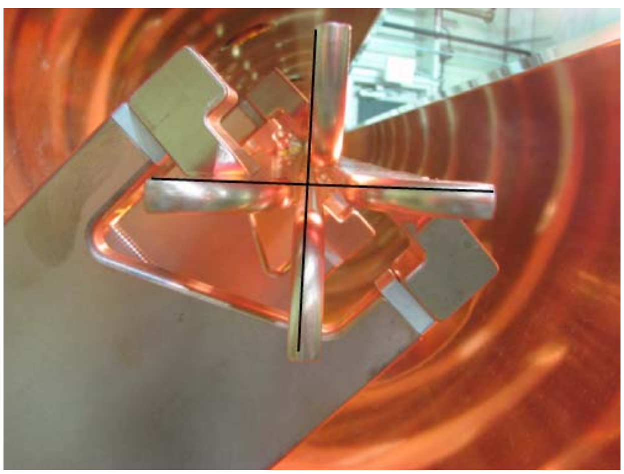


Figure 1: Shifted vanes

Each vane consists of three sections (3m overall length divided into three 1 m vanes), and the first four vanes at injection side were taken off and their curved shapes were straightened. The vane alignment was completely redone using a 3D laser tracker (API T3), and ±100μm of the error was achieved. In addition, the field distribution and the frequency were adjusted by changing the position of the shorting plates which are between the stems.

### *Beam test using the RHIC-EBIS*

The beam commissioning was started again using the RHIC-EBIS from March 2010. No obvious angle oscillation was observed. $He^{+}$, $Au^{32+}$ and $Fe^{20+}$ have been tested. Figure 2 shows the transmitted charge for $Au^{32+}$ acceleration. The orange curve is predicted by PARMTEQM and the green curve shows detected charge, including unaccelerated particles. In the low RF power region, various species with different charge state ions were transversely captured by the RFQ focusing force. The simulation curve does not include the undesired ions. The injected beam energy was scanned using $Au^{32+}$ as shown in Figure 3. The nominal platform voltage is 105 kV.

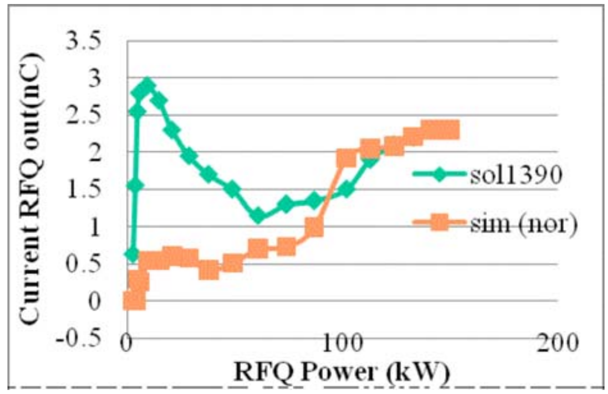



Figure 2: Measured particles after the RFQ

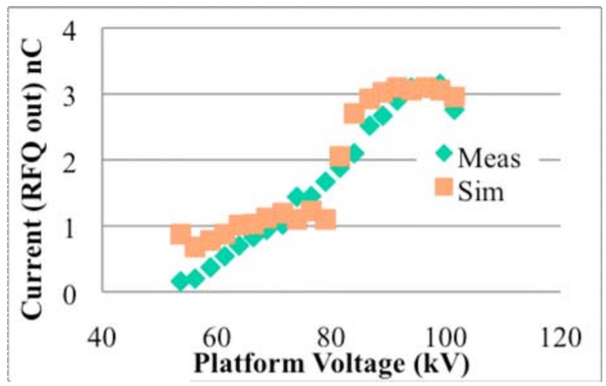



Figure 3: Injection beam voltage vs, accelerated charge detected after the RFQ

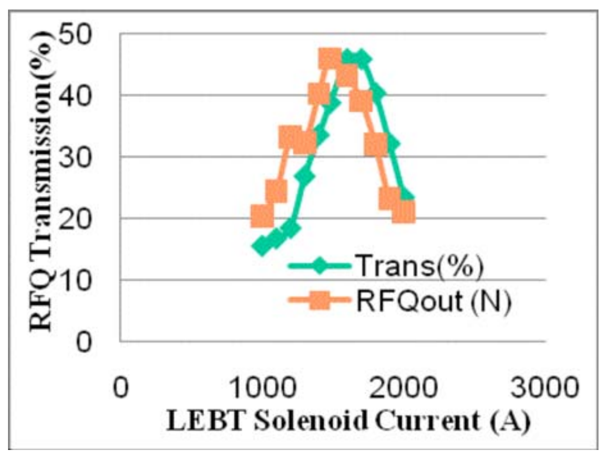



Figure 4: Beam transmission vs. focusing force of injected beam

Figure 4 shows the measured transmission efficiency of the RFQ with $Au^{32+}$ again. The values include all the charged particles. The horizontal axis is the current supplied to a focusing solenoid magnet which gives conversing beam into the RFQ at optimum current. The simulated result (orange dots) agrees well with the measured curve. $He^{1+}$ and $Fe^{20+}$ were also accelerated successfully with reasonable operating conditions.

## MEBT

An 81 cm distance between the RFQ and the IH linac is occupied by a buncher cavity (called C-1) and two doublet quads as shown in Figure 5. All the quads are identical. Due to the very short distance, no steering magnets are installed in this section. The subsequent IH linac could capture the RFQ output beams successfully and the first accelerated beam was transported to the Booster synchrotron in July 2010.

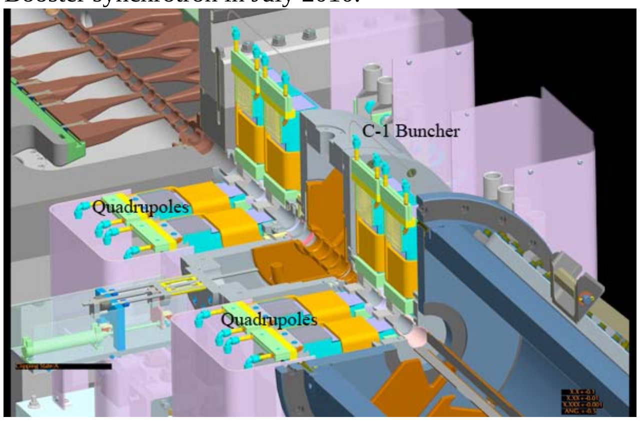



Figure 5: Cross-sectional view of the MEBT section

### *C-1 buncher*

This is the first (upstream) buncher of three bunchers in the EBIS preinjector. The vacuum enclosure is made

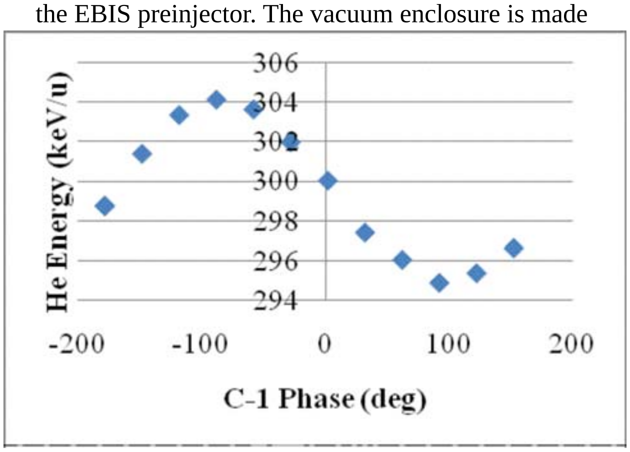
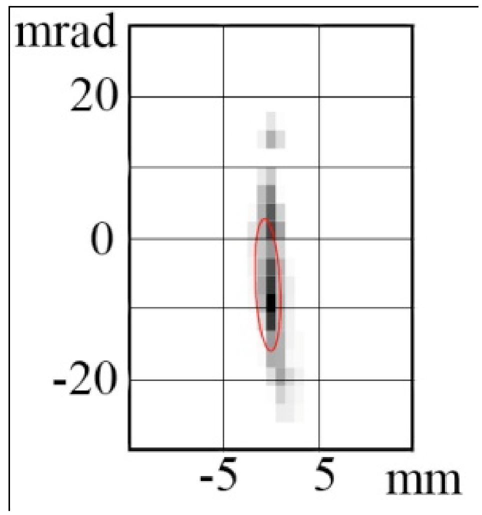



Figure 6: Energy shift of the beam vs. RF phase angle of the C-1 relative to the RFQ

of aluminum and the parts of the buncher having higher surface currents (resonating structure including drift tubes) is fabricated using solid copper. To obtain a high efficiency, a four gap π mode structure was adopted. A capacitive frequency tuner is driven by a stepping motor. As shown in Figure 6, the energy shift of $He^{1+}$ beam given by the buncher was measured by one of dipole magnets [4] which are placed just before the Booster ring. The shunt impedance was confirmed as 6 MΩ by TOF of the beam and X-ray energy detection.

### *Quadrupole magnets*

To maximize the field gradient, the pole tips are slightly cut to accommodate a 32 mm diameter beam pipe with ±0.5 mm margin. The laminated yoke thickness is 70 mm and the effective length is 82 mm at the full current (677 A) which gives 70 T/m at the center of the magnet. Each pole has a 11.5 turn water cooled coil and the inductance was estimated as 0.7 mH. Pulsed power supplies provide a 600A, 10ms flat top with a 15 ms rise time and up to a 5 Hz repetition rate. The integrated multipole components (r = 1.0 cm) were designed to be less than 0.03% of the quadrupole component. The transverse performance of the MEBT was confirmed by a slit and collector emittance scanner. Figure 7 shows the obtained emittance of $He^{+}$ at the end of the MEBT which was 0.13 π mm·mrad (normalized RMS). The gold beam also showed good




matching with 0.19 π mm·mrad.

Figure 7: $He^{+}$ beam emittance shaped by the MEBT

## SUMMARY

As parts of the RHIC-EBIS preinjector, the RFQ and the MEBT were designed and constructed. $He^{+}$, $Au^{32+}$ and $Fe^{20+}$ beams with moderate intensities from the RHIC-EBIS were accelerated as designed. With further commissioning, we expect to achieve the design goal of the RHIC-EBIS preinjector system within this year.

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