# BEAM COMMISSIONING OF THE RFQ FOR THE RHIC-EBIS PROJECT*

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*Abstract*

Beam commissioning of a new 4 rod RFQ has started at Brookhaven National Laboratory (BNL). The RFQ will accelerate intense heavy ion beams provided by an Electron Beam Ion Source (EBIS) up to 300 keV/u. The RFQ will accelerate a range of Q/M from 1 to 1/6, and the accelerated beam will be finally delivered to the Relativistic Heavy Ion Collider (RHIC) and NASA Space Radiation Laboratory (NSRL). The first beam was successfully accelerated and the bunch structures of $He^{+}$ and $Cu^{10+}$ beams were measured. The further beam tests are in progress.

## INTRODUCTION

At BNL, a new intense heavy ion pre-injector system is being built [1,2]. The pre-injector consists of an electron beam ion source, an RFQ and an inter-digital H structure (IH) linear accelerator (linac). Both the RFQ and the IH-linac are designed and fabricated by IAP, Frankfurt University [3].

The new EBIS can provide up to several mA of highly charged heavy ions from He to U. To obtain the desired charge states of the ions, the confinement time in the electron beam trap can be adjusted. Also, the beam pulse duration can be varied by changing the electric field shape along the beam trap during ion extraction. The EBIS can provide high current beams with great flexibility in ion species, charge states, beam current and pulse length.

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 |
| Outp trans. emittance 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 |

To accelerate various high current beams from the EBIS, the 4 rod RFQ will be used. The RF power will be adjusted over a wide range for acceleration of charge to mass ratio which is from 1/2 for $He^{2+}$ to 1/6.25 for $Au^{32+}$.

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The basic design parameters of the RFQ are listed in Table 1. The RFQ and the IH-linac will be aligned on the EBIS beam axis without an analyzer magnet. As a result, un-desired charge state ions and other species like hydrogen will be injected to the RFQ simultaneously, and some neighboring charge state ions could be accelerated through the end of the linac chain. A bending section just before the booster ring will finally filter the beams.

We are investigating the output beam quality of the RFQ and will try to understand the effect of the un-wanted charge state beams on the selected main beam.

## LOW POWER TEST

The RFQ was delivered to BNL in the fall of 2008. At first the RF properties were measured by a network analyzer. The loaded Q value was 2100. The RFQ has two identical tuners as shown in Fig. 1 and an overall tuning range was confirmed as from 100.574 MHz to 100.761 MHz.

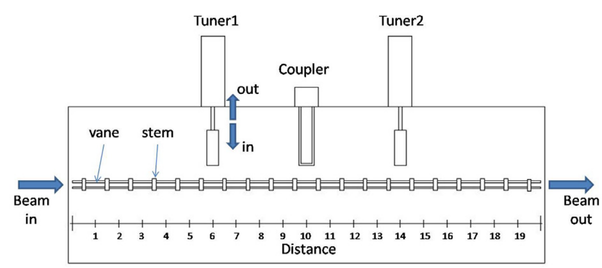


Figure 1: Frequency tuners and RFQ vanes.

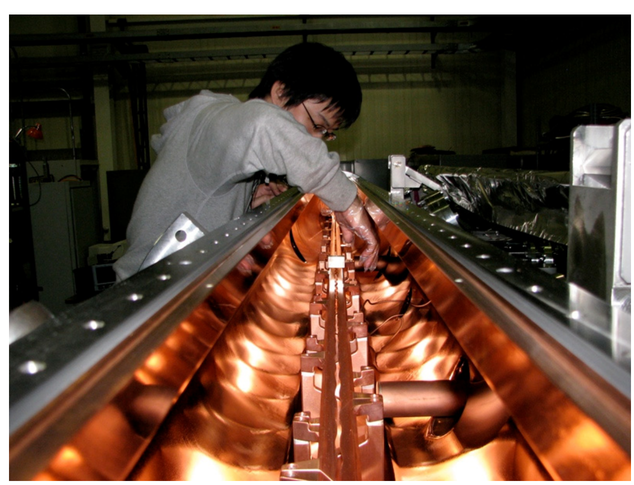

Figure 2: Field distribution measurement.

The field strength distribution along the beam axis was measured using a frequency perturbation method. The balance of the quadrupole field was not measured since it was difficult to place a dielectric material properly to each gap between electrodes. A relatively large ceramic block, 25 mm x 25 mm x 37 mm was placed at the mid points between stems on the vanes as shown in Fig. 2 and the induced frequency change was recorded.

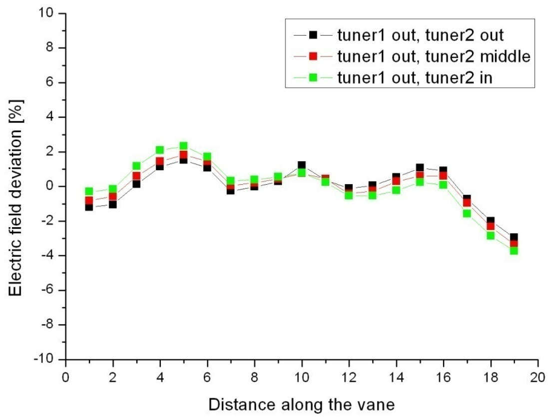


Figure 3: Field distribution along the beam axis.

Figure 3 shows the field strength distribution. The deviation was within ± 2.7 %. When the two tuners travel same length, we did not observe obvious changes in the distribution. An extreme case is shown in the figure. The numbers on the horizontal axis correspond to the position of the ceramic block indicated in Fig. 1.

## HIGH POWER TEST

The cavity was commissioned with a 300 kW RF amplifier which is usually used for another existing RFQ. We started to feed RF at low power and gradually increased it, keeping the cavity vacuum better than $10^{-7}$ Torr. It took about a half day to achieve 150 kW which is 30 % higher value than the planned power for $Au^{32+}$. While we increased the RF power, we didn't observe any discharges in the cavity. The repetition rate and pulse duration were 10 Hz and 100 µs respectively. The measured x-ray was 35 µrem/h at 150 kW of input power. We plan to measure the energy of the x-rays to identify the intervane voltage.

## BEAM TEST

In January 2009, the first beam was accelerated through the RFQ. $He^{1+}$ beam was provided from the Test EBIS source which has a half length of the electron trap of the RHIC EBIS. Between the RFQ and the source, a ceramic acceleration column, a LEBT chamber with a gridded einzel lens, and a pulsed focusing solenoid were installed. To tune the input beam emittance to the RFQ, electrostatic deflectors and the solenoid were used. The injection beam line is shown in Figs. 4 and 5.

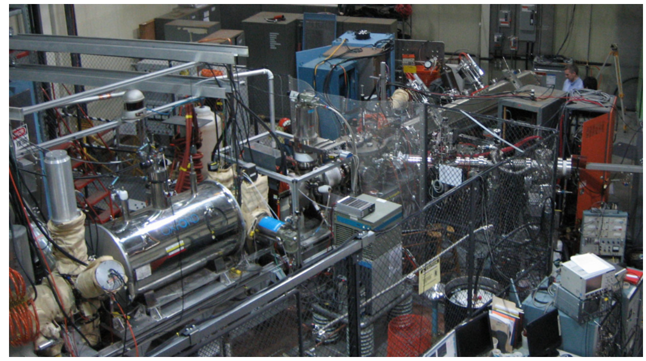

Figure 4: Photo of the beam line.

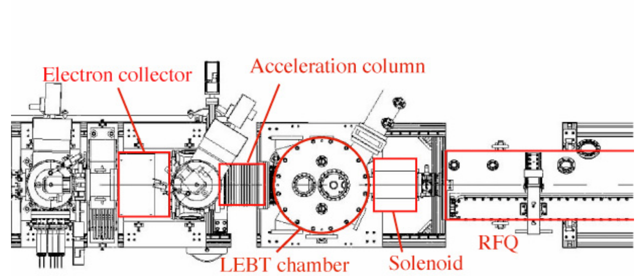


Figure 5: Injection beam line to the RFQ.

Figures 6 shows the accelerate beam currents measured by a Faraday cup which was installed just after the RFQ. The input current was 1.2 mA at a current transformer before the focusing solenoid. In addition to $He^{1+}$, the current could contain $He^{2+}$ and hydrogen. The vane voltage was scanned by changing the RF power. The black curve in Fig. 5b corresponds to the design condition of the RFQ. Unfortunately the bandwidth of the measuring system was not high enough to measure accurate bunch structure, however, we observed clearly bunched shape above the design vane voltage region. $He^{2+}$ and $Cu^{10+}$ beam were also tested and the bunched beams detected.

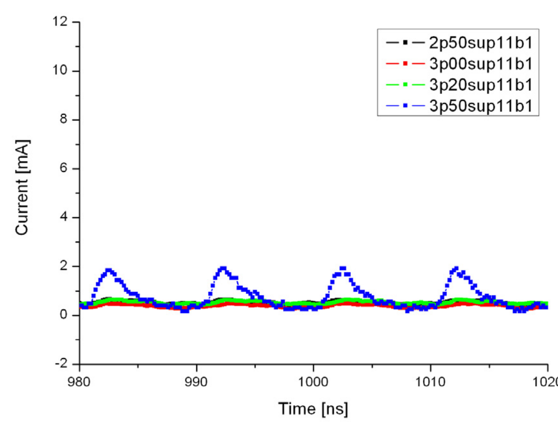


Figure 6a: Measured current after the RFQ at lower RF power.

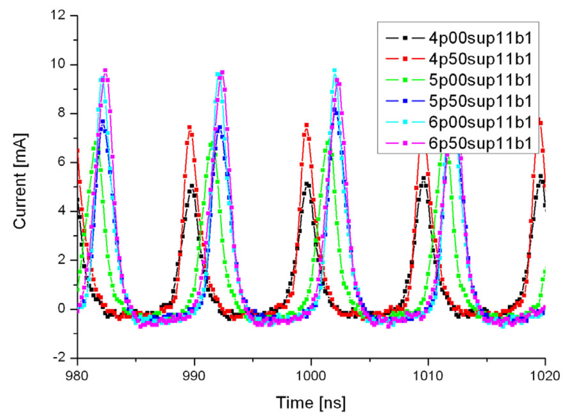


Figure 6b: Measured current after the RFQ at higher RF power.

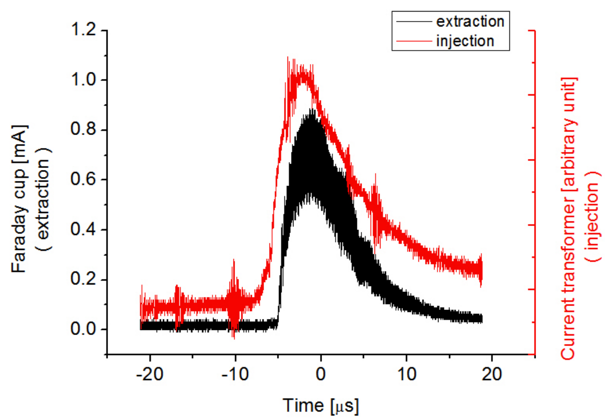


Figure 7: Beam pulse profiles.

In Fig. 7, the black line shows a macro pulse structure of the accelerated $He^{1+}$ beam current. The red line is the signal from a current transformer before the RFQ. The both signal might contain $He^{2+}$ and $H^{+}$ ions.

## BEAM ANALYSIS TEST

Since multi charged ions are simultaneously accelerated in the RFQ, it is difficult to examine detailed beam quality and the transmission efficiency of each beam. In addition, to optimize many operation parameters including the EBIS source itself and electrostatic devices before the RFQ, a completely separated single charged beam should be monitored after the RFQ. For these purposes, we are assembling an analyzing beam line. The schematic view is shown in Fig. 8.

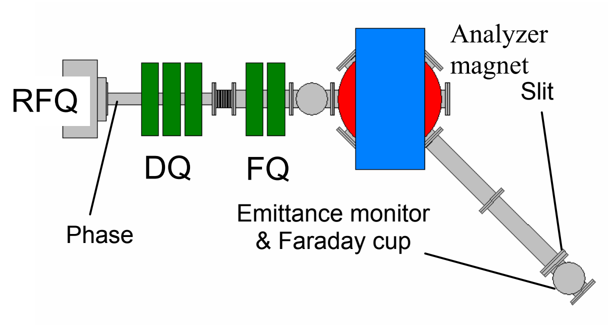


Figure 8: A beam line for analyzing multi charged ions.

The first three quads are defocusing and the last two quads are focusing. The dipole magnet has a round shape pole which is 40 cm in diameter and can induce up to 1 T for $Au^{32+}$. The beam line is close to the completion.

## SUMMARY

The RFQ for the RHIC EBIS was fabricated. The RF properties and the high power tests showed good results. Beam tests using He and Cu were carried out and the accelerated bunch structure was observed. To investigate the accelerated beam quality, further beam study is scheduled using the analyzing beam line.

## REFERENCES

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[2] J. Alessi et al., “EBIS preinjector construction status”, Proc. of the 2008 LINAC Conf., Victoria, BC, Canada, TUP120.

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