COMMISSIONING OF THE IH LINAC AND HIGH ENERGY BEAM TRANSPORT OF THE EBIS BASED PREINJECTOR FOR RHIC*

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Abstract

The EBIS based preinjector for RHIC is now being commissioned. The linac, delivered in April 2010, accelerates ions from 0.3 MeV/u to 2 MeV/u with 27 accelerating gaps, one internal quadrupole triplet, and operates at 100.625 MHz. The linac is followed by a beam transport line to Booster which includes seven quadrupoles, two bunchers, and a bend system with resolution of 500 at 2 MeV/u to select the required charge state. Diagnostics include phase probes, fast Faraday cup, adjustable slits, three sets of multiwire profile monitors, three current transformers, two Faraday cups, and two beam stops. This contribution will report results of linac tuning and cold measurements, and commissioning of the linac and high energy transport line with helium and gold beams.

INTRODUCTION

The EBIS-based heavy ion preinjector for RHIC consists a high current (10 A) electron beam ion source (EBIS) with output energy of 17 keV/u, followed by low energy transport (LEBT), 100 MHz RFQ (300 keV/u) and 100 MHz IH linac (2MeV/u) [1, 2, 3]. A 37 meter long beam transport line follows the linac, connecting to the heavy ion injection point of the Booster. This EBIS based preinjector will replace two existing Tandem Van de Graaff accelerators and an 800 m transport line. It will serve as the heavy ion preinjector for both the Relativistic Heavy Ion Collider (RHIC) and NASA Space Radiation Laboratory (NSRL). It is designed to deliver milliampere currents of any ion species (He to U) in ~10-40 μs long pulses, to allow one to four turn injections into the Booster. One unique feature of the preinjector is that species from EBIS can be changed on a pulse-to-pulse basis, by changing the 1+ ion injected into the EBIS trap from the external ion sources. The switching time for the magnets in the beam transport line following the linac will be 1 second. Table 1 shows high-level parameters for the preinjector.

Table 1: High Level Preinjector Parameters

Ions	He – U
Q / m	≥ 1/6
Current	> 1.5 emA
Pulse length	10-40 μs
Rep rate	5 Hz
Final energy	2 MeV / u
Time to switch species	1 second

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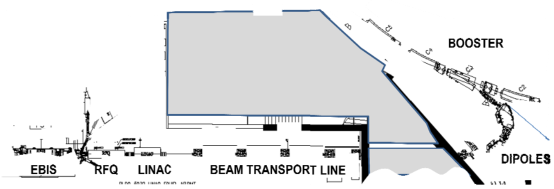

Figure 1: Layout of the EBIS-based heavy ion preinjector.

IH LINAC

The IH Linac was designed by IAP, Frankfurt. The linac is designed for a beam current of up to 10 mA with q/m > 1/6. Linac was design to provide low emittance growth and low (0.05 %) momentum spread. The design uses KONUS beam dynamics, but includes the possibility of shifting of the phases of last two gaps to -90 degrees in order to achieve a lower momentum spread. PINK [4] fabricated the cavity, and the internal quadrupole triplet was built by Bruker [5]. Figure 2 depict the internal part of the IH linac during initial rf measurements at IAP Frankfurt. Table 2 show main parameters of this linac.

Initial low level rf measurements were accomplished at IAP Frankfurt. Figure 3 shows the measurements of gap voltage compared with design.

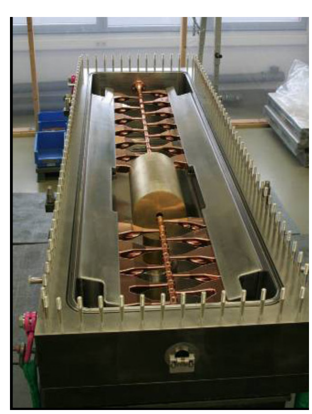

Figure 2: IH linac during initial rf testing at IAP Frankfurt, Germany.

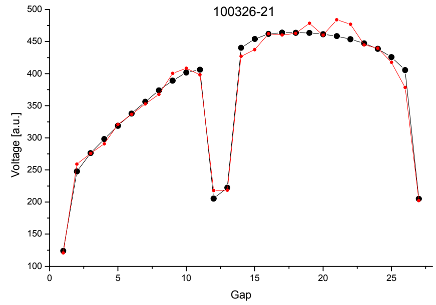

Figure 3: Gap voltages - design (BLACK) and measurement (RED) as function of gap number.

Table 2: Parameters of the IH Linac

Input energy	300 keV/u
Output energy	2 MeV/u
Q / m	> 1 / 6
Frequency	100.625
Cavity Length	2.46 m
Number of accelerating gaps	27
Quality factor	10,000
Inter quadrupole triplet	1
Power (with beam loading)	~ 300 kW

The linac was delivered to BNL in April 2010. It took about one week to condition to full power. The x-rays from the linac are low enough to work around the linac while it is operating full power at our ~0.1% duty factor.

HIGH ENERGY BEAM TRANSPORT

The High Energy Beam Transport (HEBT) line from the IH linac to Booster injection includes is a ~17 meter section in the linac building, transport through a ~8 meter thick shield wall, and then inside the Booster tunnel a ~12 meter transport, including two dipoles, to inject beam into the Booster at the same location as beam coming from the Tandems. The two identical dipoles each have a bend angle of 72.5 degrees, a 13.5 cm gap, 1.3 meters bend radius, and 1T maximum field These magnets are laminated to allow the required 1 second field change time for different ion species. This beam line has several constraints in order to fit into the existing facilities. (1) It has to inject beam in the same location at the Tandem which required a high bending angle, and since it had to fit inside the Booster enclosure, one had to make bend radius rather small compare to other focal lengths in the transport line. (2) It has spaces without any optics components and diagnostic to accommodate the 8 meters thick shield wall and 6 meters of space needed for the 200 MeV linac shield door. (3) The last element in the line is an existing inflector with horizontal aperture only 17 mm, designed for the Tandem beam, which has much lower emittance, and which is a bottle neck in this line. (4) The linac uses a triplet for transverse focusing while the rest of the line use FODO lattice. (5) The fact that ion species are not separated until the dipole makes tuning of the preinjector rather hard. To accommodate these constraints the resulting line has one quadrupole triplet, 7 quadrupoles, two bunchers, three horizontal steerers and four vertical steers. The quadrupole triplet was design and built at BNL and both bunchers were design and built by IAP Frankfurt. Due to time constraints the second buncher (C-3) is being installed in September. Diagnostics include phase probes, fast Faraday cup, adjustable slits, three sets of multiwire profile monitors, three current transformers, two Faraday cups, and two beam stops. Figure 4 show the TRACE3D output for this line. Figure 5 show the photograph of the line in the linac side of the line.

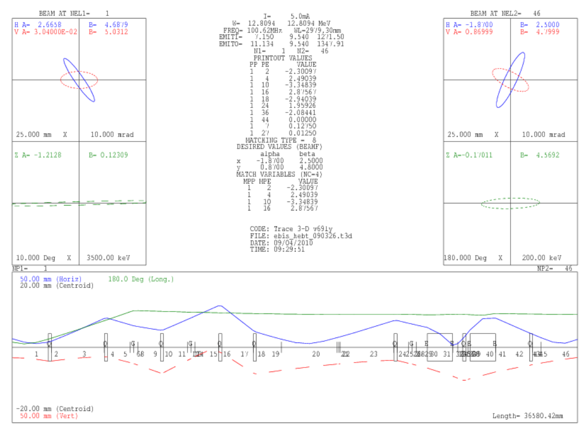

Figure 4: TRACE3D output for the HEBT.

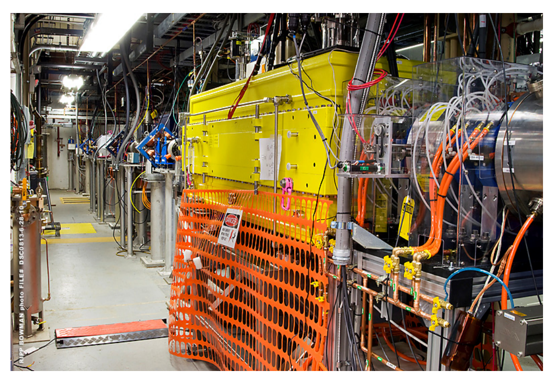

Figure 5: View of the HEBT from the RFQ. The yellow structure is the linac.

BEAM COMMISSIONING

The linac was installed and rf conditioned by June 11th. We then started beam commissioning with He^{+1} because, since ion species are not separated until they reached the dipole in the HEBT, it was convenient to initially accelerate only one ion specie/charge state. Once the linac was in place and connected to HEBT, beam from the RFQ was first taken to the middle of the bend, with the buncher and linac rf off. Beam was centered in the beam pipe with help of multi-wires and dipole correctors. Following this, we turned on the buncher in the MEBT line with calculated power and varied its phase while centering beam in middle of double bend and reading the current in the dipole.

Once the proper phase of the buncher was determined, the linac rf power was turned on and beam tuned to the middle of the double bend. Phase and rf power scans were made to get 2 MeV/u energy at the middle of the bend. The tuner in the linac was adjusted to get the design energy. Once the proper energy was achieved phase and rf power scans were again made. Figure 6 shows examples of scans, compared with simulations.

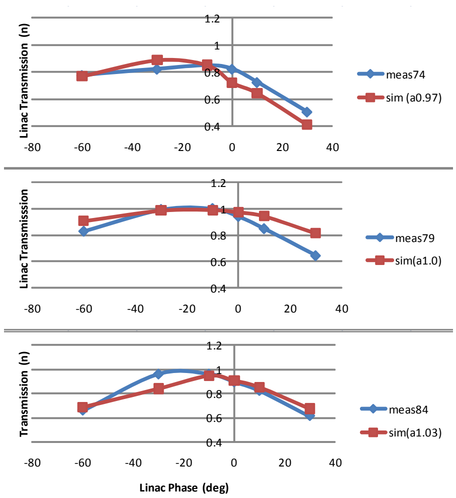

Figure 6: Linac phase scans with different rf amplitude, compared with simulations, 97%, 100% and 103%.

On July 2nd 2010, helium beam from the EBIS preinector was circulated in the Booster. Figure 7 shows the signal from a BPM in the Booster as the beam passes. As the beam circulated in the injection porch, it became de-bunched. By counting how many turns it took the beam to debunch, one can calculate the momentem spread of the beam. The measured momentem spread in the Booster for He^{+1} beam is $2x\ 10^{-4} \pm 1.0\ x\ 10^{-4}$.

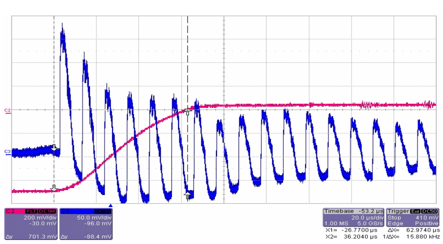

Figure 7: Signal from pick up in the Booster as the helium beam passes by on every turn. (only 17 turns are shown of >1000 circulated in the Booster).

On July 12, 2010 we started commissioning with Au^{+32} to satisfy the project's CD-4 requirement. On August 19, 2010, accelerated gold ions were transported to the middle of the dipoles in exess of the CD-requirement. Table 3 shows the main parameters for the helium, gold and iron. On August 20th commissioning with iron ions was started, and on August 30 the CD-4 goal for Fe^{+20} ions was exceeded. Gold ions (Au^{+32}) required maximum capacities of all the sub systems (i.e. platform voltage, RFQ power, linac power, dipole current) except EBIS confinement time. The iron ions needed the maximum (130 ms) confinement time. On August 31, 2010 we were able demostrate switching, alternating between gold and iron ions every 2s.

EBIS produces other charge states along with the desired charge state of a species, and ions from any background gas in the EBIS trap region. If these background ions are not very far in the momentem space they are transported through the RFQ and linac, and only separated after the first dipole where the resolution is about 500 at 2 MeV/u. This increases the difficulty of tuning, since if one tunes to maximize the current before dipole, you can end up maximizing the wrong ion species.

Table 3: Parameters for Helium, Gold and Iron Ions Demonstrated for CD-4

Parameter	**He^{+1}**	**Au^{+32}**	**Fe^{+20}**
q/m	0.25	0.162	0.357
Platform Voltage (kV)	68	104	47.6
RFQ Power (kW)	40	95	20
Linac Power (kW)	75	180	37
Dipole Current (A)	1415	2270	1030
Pulse Length (μs)	20	20	36
Rep. Rate (Hz)	1	1	1
Intensity (10^8)	1250	3.7	4.75
Energy (MeV/u)	2	2	2
Transmission,	75	90*	60*

RFQ input to middle of bend (*=inferred, due to multiple charge states)

CONCLUSIONS

The linac and HEBT have been successfully commissioned without any surprises, and in a much shorter time than planned. We were able to switch ion species in 2s. The intensity of the preinjector will now be worked up to its final design intensity, about order of magnitude higher, by increasing the electron current in EBIS itself and reducing the background ions by improving the EBIS vacuum. A full system bakeout is planned for September 2010.

REFERENCES

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[4] PiNK GmbH, Wertheim, Germany.
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