RESULTS OF LEBT/MEBT RECONFIGURATION AT BNL 200 MEV LINAC*

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Abstract

The low energy (35 keV) and medium energy (750 keV) transport lines for both polarized and unpolarized H^- have been reconfigured to reduce the beam emittance and beam losses out of the 200 MeV Linac. The medium energy line in the original layout was 7 m long, and had ten quadrupoles, two beam choppers, and three bunchers. The bunchers were necessary to keep the beam bunched at the entrance of the Linac. About 35% beam loss occurred, and the emittance growth was several fold. In the new layout, the 750 keV line is only 0.7 m long, with three quads and one buncher. We will present the experimental result of the upgrade.

INTRODUCTION

The Brookhaven National Laboratory (BNL) 200 MeV drift tube linac (DTL) provides H- beam at 6.67 Hz, 200 MeV for the polarized proton program at Relativistic Heavy Ion Collider (RHIC) and 116 MeV for Brookhaven Linac Isotope Production (BLIP) [1]. The RHIC program needs 2 pulses every AGS cycle (~4 sec), one for injection into Booster and other for polarization measurement in the 200 MeV polarimeter located in the high energy transport line (HEBT). The rest of the pulses go to BLIP. The requirements for these programs are quite different and are the following. (1) RHIC: 200 MeV, 200 µA beam current, up 400 µs pulse length, polarization as high as possible and emittance as low as possible, (2) BLIP: 116 MeV, 450 µs pulse length, current as high as possible (~40 mA), uniform beam distribution at the target, and losses as low as possible. Prior to the upgrade, Linac transmission efficiencies from source to tank 9 were about 35% for the high current and 50% for the polarized beams and emittance growth several folds for the both beams.

The emittance is one of the most fundamental parameters for any accelerator and in particular for the colliders. To reduce the emittance growth in the linac, low energy and medium energy transport lines were reconfigured as proposed in 2004 [2].

LEBT AND MEBT BEFORE RECONFIGURATION

Figure 1 depicts the layout of the Low Energy (LEBT) and Medium Energy (MEBT) Transport Line. The LEBT for the high intensity was about 1 meter long, had two solenoids and one pair to steering magnets in each plane.

The transmission efficiency from source to RFQ exit was about 70%. The LEBT for polarized H- was about 3.5 meters long and had two einzel lenses, four quadrupole magnets, and two bending magnets (-23.6 and 47.4 degrees). The angles of bending magnets are chosen such the H- polarization was in the transverse plane before entering the RFQ. The solenoid in the MEBT brought the polarization to the vertical direction before entering the Linac. The transmission efficiency for polarized H- was about 80% from the source to the RFQ exit.

The medium energy beam transfer line (MEBT) was about 7 meters long and had ten quadrupoles, one solenoid for spin rotation, three buncher, two choppers (slow and fast), beam collimator in the each plane, a diagnostic box, beam stop, and two pairs of steerers in each plane. The bunched beam emerging from RFQ was poorly bunched as it entered in the linac in spite of three bunchers. The PARMLA simulations showed that in the process of capturing beam in linac tank 1, about 35 % of the beam was lost, and the emittance growth was several fold [2].

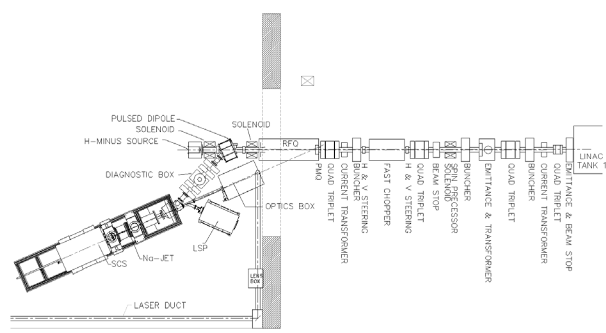

Figure 1: Layout of LEBT and MEBT before reconfiguration.

LEBT AND MEBT AFTER RECONFIGURATION

Figure 2 depicts the LEBT and MEBT after reconfiguration. The MEBT length was reduce from 7 meters to 70 cm. It has three quadrupoles, two pairs to steerers in each plane, one buncher and a current transformer. Due to physical constraints the polarized source could not be moved, and linac tanks cannot be moved, therefore we ended up with a long LEBT. The LEBT for the high intensity beam is about 4 meters long and has two solenoids, two sets of steerers in each plane, a beam stop, collimators in the each plane, a slow chopper, and an einzel lens before the RFQ. The einzel lens was tested with the RFQ for the transmission in

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2007, and gave about 80% transmission through the RFQ for high intensities and 90% for the polarized H-. The LEBT for polarized H- has four einzel lenses, one solenoid, one 23.7 degree dipole magnet, and three sets of steerers in each plane. The angle of the dipole, in combination with the solenoid, is chosen such that the direction of the polarization is vertical before the beam enters in the RFQ.

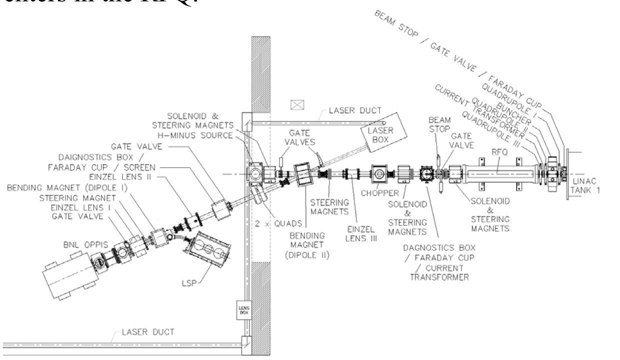

Figure 2: Layout of LEBT and MEBT after the reconfiguration.

In the MEBT (Figure 3), we have used the quadrupoles from the LEDA project with solid core. The power required for the buncher was about 10 kW, but the buncher RF power source was capable of only maximum of 5 kW. The buncher was modified by adding an additional feed loop to each of the cavity's two-¼ wave resonator arms. The buncher is now be powered by two 7651 tetrode, 5 kW power amplifiers. Each amplifier system is independently phase adjusted and power combined in the buncher. One of the additional loops is used for feedback for both phase and amplitude stabilization loops about both amplifiers. Ceramic RF windows have been purchased, but not yet installed, to replace the original rexolite RF windows. This will improve the long-term reliability at the higher power levels. We have successfully operated the buncher at 8 kW's of RF power, 4 from each amplifier system. During previous operating years up to 3 bunchers were required with the highest power requiring 3.5 kW.

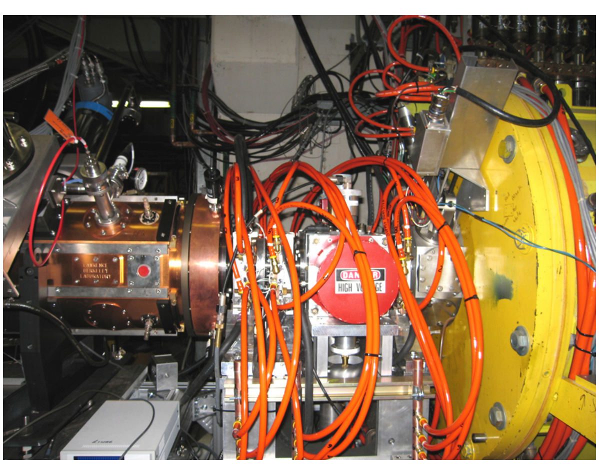

Figure 3: Photo of 70 cm long MEBT.

COMMISSIONING OF LEBT AND MEBT

First, LEBT was commissioned with polarized protons. With the current measured on a Faraday cup just out of RFQ, the transmission from source to RFQ exit was 100%. Then we commissioned MEBT with polarized proton, and current was measured just before linac, also on a Faraday cup, and the transmission was 70 % from the source to the linac.

With up to 100 mA out of the ion source, we measured only 30 mA in front of RFQ and about 17 mA out of RFQ, and big current fluctuations during the 400 µs long pulse. Various configurations were then tried, by changing second solenoid location, but neither current transmission efficiencies or the current fluctuations improved. The transmission efficiencies were almost same for wide range of currents (source current 50 mA to 100 mA) and energy (20 keV to 35 keV). One more solenoid was added, now having three solenoids and an einzel lens in front of RFQ. With this, one got about 45 mA in front of the RFQ and 22 mA after the RFQ. With einzel lens #3 turned on (supposed to be used for the polarized beams only) we got 50 mA in front of the RFQ and 25 mA after the RFQ. Finally, the einzel lens before the RFQ was replaced with one of the solenoids, and the other solenoid reconfigured such that distance between the RFQ and the 2nd solenoid is approximately same as before the reconfiguration. This configuration resulted in 35 mA after the RFQ. When Xe gas was introduced into the beam pipe, one got 65 mA in front of the RFQ and 42 mA out of the RFQ. We are now operating LEBT at an average pressure of 3.7 x 10^{-6} Torr. The ionization cross section for the Xe gas is 8 x 10^{-16} cm^{-2} and the required pressure for the Gabovich critical density[4] for complete neutralization is 3.6 x 10^{-6} Torr (Xe gas density of 1.2 x 10^{11} cm^{-3}). We measure a neutralization rise time about 40 µs, and the calculated value is about 38 µs. The stripping cross section for 35 keV H- is about 4 x 10^{-15}, which gives about 20% stripping loss for the 4 meter long LEBT, while about 32% loss in the LEBT is measured. Table 1 summarizes commissioning of LEBT for high intensity.

Table 1: Summary of LEBT Commissioning for High Intensity

Configuration	Before RFQ	After RFQ
2 sol. + ein. lens	30 mA	17 mA
3 sol. + ein. lens	45 mA	22 mA
3sol. + ein. lens#	50 mA	35 mA
3 sol. + ein. lens + Xe gas	65 mA	42 mA
#Solenoid in front of RFQ and Einzel lens before chopper		

The next stage of high intensity commissioning was to send the beam through linac. We energized only tank 1 and the quadrupoles of all 9 tanks, and dump the 10 MeV beam on a beam dump after tank 9. While simulations predicted 100% transmission from the RFQ through tank 1 at 10 kW buncher power, the actual power was limited to 8 kW. At this power, the maximum current out of linac was about 32 mA (76% transmission), in agreement with simulations. We measure no beam losses in the MEBT. Figure 4 show the linac output current vs. buncher power.

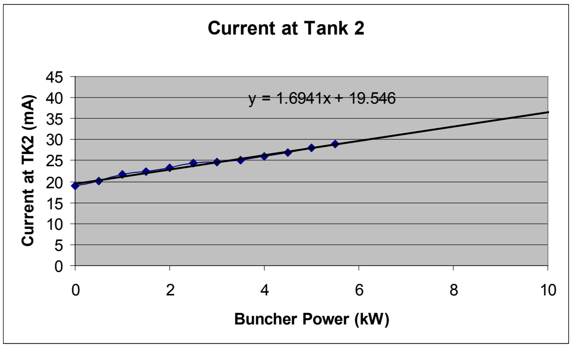

Figure 4: Linac output current as function of buncher power.

RESULT AND DISCUSSION

The main purpose of the upgrade was to reduce the emittance out of linac for the polarized H- and improve the transmission efficiencies. Table 2 compares the emittance and linac transmission efficiencies before and after the upgrade.

Table 2: Emittance and Transmission Efficiencies of the Linac. Transmission Efficiencies Measured as Ratio of Linac Output Current to Source Current

Year	ε_X, N, 95% (π mm mr)	ε_Y, N 95% (π mm mr)	Trans. (%)
Before upgrade	10.7	15.9	50-55
After upgrade	4.5	5.5	65-70

The reduction in emittance is seen in every step of the RHIC accelerator chain. Another, unexpected, improvement this year was the reduction in the background for the polarimeter at 200 MeV in the high energy transport line. Since the RFQ acceptance is about 2π mm mrad (normalized), there is still some room to improve the linac output emittance by tuning the transverse matching in the DTL tanks.

For the high intensity, BLIP is running about 72 μA average current on the target, compared to 71 μA last year, but.this year the duty factor for the BLIP is about 6% higher than last year. Figure 5 shows a comparison of the beam foot-print at the target before and after the upgrade. Radiation due to beam losses has been reduced everywhere, compared to before the upgrade. The temperature of carbon collimators in front of BLIP target, used to measure beam halo, is about 75° C, compared to 160° C last year. While the beam current outside 2" diameter on the BLIP target used to be about 8%, measurements after the upgrade now show, it is 0%.

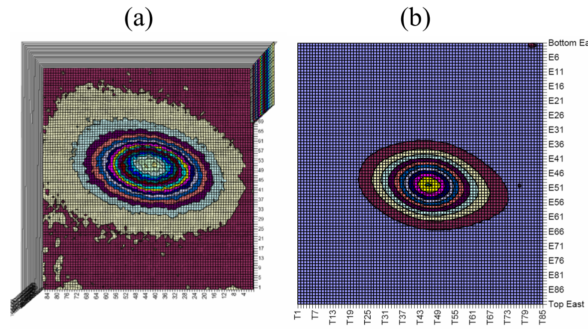

Figure 5: Beam foot print at the BLIP target (a) before and (b) after reconfiguration of LEBT/MEBT showing the same number of contours.

Some issues still have to be resolved: (1) poor transmission in the LEBT, (2) insufficient buncher power, (3) steering in the MEBT, and (4) quadrupole and its power supply for the MEBT.

We plan to further modify the LEBT for high intensity to improve transmission. The length of the high intensity beamline will be reduce by factor of 2 and will have two solenoids, two quadrupoles, one set of steerers in each plane, a chopper and one 45° dipole. The optics for polarized H- will remain almost the same, with a slight reconfiguration of the solenoid and einzel lens. We are now testing the buncher with higher RF power using a different RF power source. We will reinstall all the steerers and use the quadrupoles similar to those used in EBIS MEBT [6].

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