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# DISCLAIMER

# 200 MeV H- LINAC UPGRADE AT BROOKHAVEN*

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*Abstract*

The 200 MeV H- linac has been operational for the last 45 years providing beam for the Physics and isotope programs. Currently we are upgrading the Linac for improved reliability and integrated intensity. Recently we have replaced the 7651 tubes with solid state RF amplifiers. In addition, the low level RF system and Timing system were upgraded and new beam loss monitors were installed which are sensitive at low energies. We have future plans to upgrade the diagnostic and power supply systems. In order to achieve higher average current for the isotope program, it is plan to increase the beam pulse length from 450 us to 900 us. This will require modification to the RF and all pulse power supply systems.

## INTRODUCTION

The Brookhaven National Laboratory (BNL) 200 MeV drift tube linac (DTL) was built in 1970 [1] with following design parameters for proton: input energy 0.75 MeV, output energy 200.3 MeV, frequency 201.25 MHz, peak beam current 100 mA, beam pulse length (max) 200 µs, RF pulse length 400 µs, pulse repetition rate (max) 10 Hz. Over the 45 years of linac operations, it has gone through several improvements. The major upgrades were; (a) switch to 5 Hz operation [2], (b) change proton to $H^-$ [3], (c) addition of polarized $H^-$ source [4], (d) replacement of the Cockcroft-Walton by Radio Frequency Quadrupole (RFQ) [5], (e) new timing system [6], (f) new 12 inches pressurised coax system [6], (g) RF system improvements [6], new 50 kV power supply, eliminating of DC charge control at 60 kV, new RF control system, phase and amplitude servo redesign, (h) new polarized source OPPIS source and its upgrade, and [7,8], (i) reconfiguration of 35 keV and 750 keV transport lines [9,10,11,12,13].

At present linac provides $H^-$ beam at 200 MeV to polarized proton program for Relativistic Heavy Ion Collider (RHIC) and 66-200 MeV to Brookhaven Linac Isotope Production (BLIP). The RHIC program needs two pulses every AGS cycle (~4-6 sec), one for injection into the AGS booster and other for 200 MeV polarization measurements located in the High Energy Beam Transport line (HEBT). The rest of the pulses from high intensity source are delivered to BLIP. Requirements for these programs are quite different and they are following. (1) RHIC: 200 MeV, 600 µA beam current, up 400 µs pulse length, polarization as high as possible and emittance as low as possible, (2) BLIP: 66-200 MeV, 450 µs pulse length, current as high as possible (~55 mA), uniform beam distribution at the target, and beam losses as low as possible. Many of subsystems of the linac are 45 yeas old and need to be replaced. Three upgrade programs; reliability, intensity, and beam raster [14,15], are in progress. Here, we will discuss only intensity and reliability upgrade program.

## RELIABILTY UPGRADE

The reliability upgrade program continuing for last two years, it include following system: LLRF, beam loss monitor systems, control system, timing system and RF systems.

### *Radio Frequency*

We have replaced 5 kW Tetrode 7651, one of six tubes in amplifiers chain, by solid state amplifies last year. It is very reliable and down time for these amplifiers is reduced to zero due to this change

### *Low Level Radio Frequency*

The original Analog Low Level RF system is being replaced with, state of the art, digital controllers. The new system consists of a Cavity Controller at each RF Local Control Station (LCS) fiber optically connected to the Update Link Master and clock fan-out chassis located in the Linac Control Room (LCR). The system takes in forward power and cavity voltage feedback to generate phase and amplitude closed loop-operating set points. System control and monitoring computers have also been installed at each LCS and the LCR. The control system interface also allows control and monitoring from off site-computers and smart phones. At this time the first 5 Linac cavities have been converted to DLLRF and Mods 6 through 9, the RFQ and MEBT Buncher to be converted during the 2016 Summer Shutdown. The system can also be expanded to include RF system Pulsed Logic, RF inter-stage match monitoring and system malfunction interlocks to safely inhibit the beam.

### *Timing System*

The National instruments VXI8000 system, Window95 based, was replaced with FEC MV31000 controller with ADO. There were minor hardware changes made to the Interface logic of the LINAC Timing System that would accommodate both systems, which are VME based. The software interface upgrade utilized PET with SyndiViewer as a custom GUI interface based on PET information. The user interface was upgraded by converting the C code used by the NI VXI8000 system into the FEC MV3100 system

### *Control System*

The existing Datacon System at LINAC is being replaced by EFC and V202 systems in order to improve the speed of data transfer. This improvement gives greater flexibility to the timing of the LINAC Quads and improved reliability of the set point and read back performance of the Quads. The read back of parameters is completed by the ADC 3122 on the event LT0 from the LINAC Event Link. LT0 is decoded from a V202 channel and provided to the ADC 3122 external input trigger port. LINAC User read backs of the output of devices is accomplished at the LINAC repetition rate of 150 msec. The analog output reference provided to power supplies is completed by the DAC 4140 module. The set points are provided on the event LPP from the LINAC Event Link. The event LPP is decoded by a V202 channel and provided to the external input trigger port of the DAC 4140 module. The operation of the Quad power supplies was tested at MOD5 successfully with a new method of providing set points and obtaining read backs at the LINAC repetition rate.

### *Beam Loss Monitors*

We are adding beam loss monitor for low energy operation of BLIP. BLIP wants to run at 66 MeV, the existing long radiation monitors are not sensitive for this low energy. We have tested (shielded with lead and cadmium) scintillator BC-400 for first three tanks and first bending magnet in the BLIP line. Figure 1 shows shielding configuration of the scintillator.

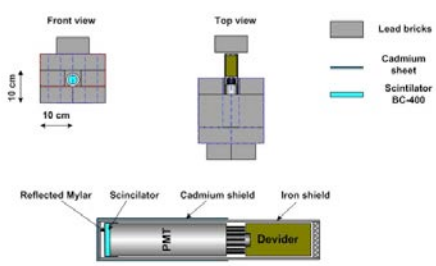


Figure: 1: Lead and cadmium shielding configuration around scintillator BC400.

These detectors are very sensitive. They were able to catch losses due to gas stripping of H- during short vacuum spike from the ion pump. Based on the pressure changes in the DTL tank, we could calibrate the detector count per nA beam loss. With help of these BLM, linac losses are reduced by order of magnitude.

## INTENSITY UPGRADE

The average current delivered to BLIP has been increasing steadily over the years as shown in Figure 2. To increase the isotope production, there is strong desire to increase the linac current by factor of two by increasing the pulse length of beam. Accelerator improvement plan (AIP) was approved for phase I of intensity upgrade in 2014. Phase I includes 15 % (5 % in the peak current and 10% in the beam pulse length) increase in average current and evaluations of the subsystem for doubling the current. Table 1 summarizes linac parameters for intensity upgrade Phase I (2014), operating 2016 and proposed to increase the intensity by factor of two, Phase II.

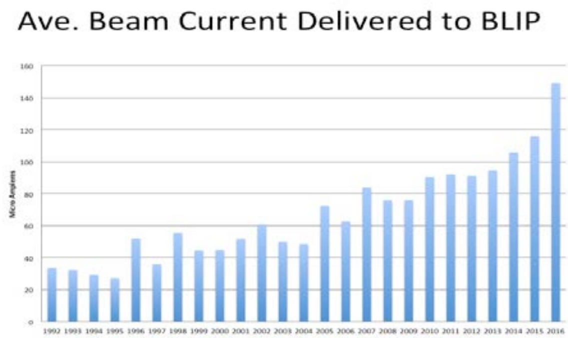


Figure 2: The average current delivered to BLIP has been increasing steadily over the years

Table 1: Linac Parameters for Intensity Upgrade Phase I (2014), Operating 2016 and Proposed to Increase the Intensity by Factor of Two, Phase II.

| Parameter | Phase I(goal) | Operation 2016 | Phase II (goal) |
|---|---|---|---|
| In. Energy (MeV) | 0.75 | 0.75 | 0.75 |
| Out. Energy (MeV) | 200 | 200 | 200 |
| Peak Cur. (mA) | 45 | 55 | 45 |
| **Beam PL (μs)** | **490** | **470** | **900** |
| **RF PL (μs)** | **650** | **620** | **1100** |
| Frequency (MHz) | 201 | 201 | 201 |
| Repetition Rate (Hz) | 10 | 6.67 | 6.57 |
| Ave. Current (μA) | 140 | 165 | 250 |

### *Phase I Results*

We have optimized Magnetron ion source operating parameter linac extraction voltage, gas flow and caesium temperature to maximize ion source and successfully increase the output current of ion source reliably to 110 mA from 90 mA. Optimized parameters are, extraction voltage 36.1 kV, caesium temperature 100° C and source pressures of 3. $10^{-6}$ Torr.

To transport such high current to RFQ, xenon gas is introduced to 2 meter long low energy beam transport to charge neutralized the H- beam. We maximized integrated beam current at 200 MeV by controlling the pressure in the LEBT. A typical pressure in the LEBT is about 4.2 x $10^{-6}$ Torr and in source about 3.6 x $10^{-6}$ Torr for maximum integrated current at the 200 MeV. Corresponding rise time about 52 μs and losses about 16%, assuming background gas 90% xenon and 10 % Hydrogen. Figures 3 shows the pulse shape before and after the xenon gas injection [16].

About 40 μs beam width was gain by placing beam about 40 μs earlier in the RF-envelop without increasing the total RF width.

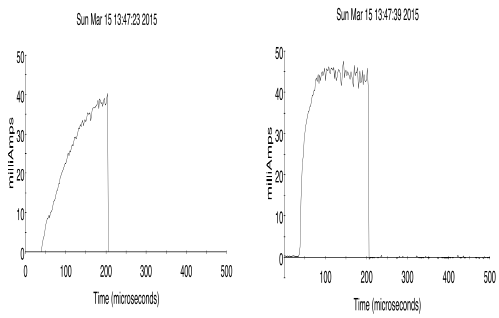


Figure 3: Pulse shape at 200 MeV without injection of the neutralizing gas in the LEBT (left) and with xenon gas (right).

## *Evaluation of subsystems for double the pulse length*

**Ion Source** To achieve 900 µs beam pulse width ion source have to produce it first. We have demonstrated 1 millisecond long pulse from the source (figure 4) at the test stand.

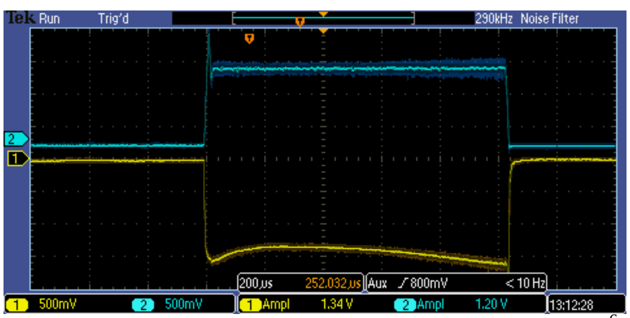


Figure 4: 1ms discharge, vacuum in source box ~5.0x$10^{-6}$, yellow trace (1) discharge voltage, blue trace (2) discharge current (~12A).

**RF System** The stand-by 10th RF system was modified to operate at an RF pulse width of 1100 µs. This was accomplished by: (1) Increasing the 250 kW driver capacitor bank from 25 to 40 µF by replacing original capacitors with ten 4uF capacitors. (2) Increasing 7835-power amplifier anode power supply capacitor bank from 50 to 84 µF by replacing original capacitors with thirty-two 2.62 µF capacitors. (3) Several elements of the Modulator that supply pulsed dc power to the anode of the 7835 RF power amplifier were required to be redesigned to function at the wider pulse width. A prototype of each unit was built and successfully tested in the $10^{th}$ RF system. They are listed below: (a) 4CW 25,000 Anode Power Supply (3kV) (b) 4CW 25,000 Cathode Power Supply (4kV) (c) Modulator A7 Low Level Electronics.

**Pulsed Magnet Power Supply System** Modification of existing quadrupole power supplies was evaluated and it was determined it will be more cost effective to implement a complete redesign of the supplies with modern electronic components that do not use the "resonant" charge approach. Contact has been made with Power Supply vendors and preliminary design proposals are being evaluated and initial results indicate requirements can be readily met.

**Cooling Requirements** Tests were done on a spare quadrupole magnet to evaluate magnet water-cooling requirements for the increased duty factor and it was found increased water-cooling is not required. Calculations have been completed for a "high power" Accelerating cavity and indicate existing water-cooling flows and pressures are sufficient to maintain dimensional stability under the planned increase in duty factor.

**Condition of Existing Cooling Channels** The conditions of water quality and flow channels were evaluated for two typical cavities and only minor anomalies were found. Measurements are planned with sensitive instrumentation to verify calculations.

## REFERENCES

[1] G. W. Wheeler *et al*, "The Brookhaven 200 MeV proton linear accelerator", Particle Accelerator, 1979, Vol. 9, pp. 1-156.

[2] N. M. Fewell *et al*, "Operation of the Brookhaven 200 MeV Linac", 1979 Linac Conference, Montauk, NY, pp 83.

[3] R. L. Witkover, *et al*, " Conversion of the AGS linac to H- Acceleration", PAC 1983, pp 3010.

[4] Y. Makdist *et al*, " Acceleration of polarized H- in the BNL 200 MeV Linac" PAC 1985, pp 3166

[5] J. G. Alessi *et al*, " Performance of the new AGS RFQ Preinjector', PAC 1989, pp 999.

[6] J. G. Alessi, *et al*, "Upgrade of the Brookhaven 200 MeV Linac", Linac 1996, pp 773.

[7] A. Zelenski, *et al*, " Optically Pumped Polarized H- Ion Source for RHIC Spin Physics", Rev. Sci. Ins. 73, 2002, pp 888.

[8] A. Zelenski *et al*, " The RHIC Polarized Source Upgrade", PAC 2013, Pasadena, CA, USA, pp 49.

[9] D. Raparia, *et. al.*, "Proposal for Reduction of Transverse Emittance of BNL 200 MeV linac", Linac 2004, Lubeck, Germany, 2004

[10] D. Raparia, *et al*, "Results of LEBT/MEBT Reconfiguration at BNL 200 MeV Linac", PAC09, Vancouver, Canada.

[11] D. Raparia, *et al.*, "Low and Medium Energy Beam Transport Upgrade at BNL 200 MeV Linac", Linac 2010, Tsukuba, Japan

[12] D. Raparia *et al*, "Changes in LEBT/MEBT at the BNL 200 MeV Linac", PAC 2011, New York.

[13] D. Raparia, *et al*, "Improvements at the BNL 200 MeV Linac", Linac 2012, Tel-Aviv, Israel.

[14] D. Raparia, *et al*, "Reducing Current Density for the BLIP Target at Brookhaven 200 MeV Linac", Linac 2014, Switzerland

[15] D. Raparia, et al, "Reliability and Intensity Upgrade for Brookhaven 200 MeV LINAC" Linac 2014, Switzerland

[16] D. Raparia, et al, "Charged neutralized low energy Beam transport at Brookhaven 200 MeV Linac" Review of Scientific Instruments, 87, 02B935 (2015).