

THE LANSCE ACCELERATOR MODERNIZATION PROJECT FRONT-END PHYSICS DESIGN AND MODEL*

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Abstract

The Los Alamos Neutron Science Center (LANSCE) accelerator at Los Alamos National Laboratory (LANL) delivers different beams to multiple experimental stations simultaneously. These beams have different intensity and time structure. The LANSCE Accelerator Modernization Project (LAMP) seeks to upgrade the technology in the front-end while preserving the unique capabilities of LANSCE. LAMP seeks to replace the two 750 keV Cockcroft-Waltons with a single RFQ, and a new 100 MeV DTL. New low-energy and medium-energy beam transport lines are necessary to produce the required LANSCE beam patterns. This contribution describes design process and the current state of the LAMP front-end physics model.

INTRODUCTION

The LANSCE accelerator facility at LANL is a pulsed radiofrequency accelerator that can produce and deliver multiple beam “flavors” with different intensity and temporal structure, simultaneously, to five different experimental facilities [1]:

- Isotope Production Facility (IPF) target receives 250 μA of H^+ beam at 100 Hz.
- Lujan Neutron Science Center (Lujan) target receives a 625 μs macro-pulse that is accumulated in the Proton Storage Ring (PSR) into a 290 ns pulse. The beam repetition rate is 20 Hz.
- Two other experimental stations receive the Lujan macro-pulse without accumulation in the ring, with different bunch train patterns and on a single-shot mode.
- Target 4 receives a single H^- , 1 ns high-intensity bunch every 1.8 μs for the duration of a 625 μs macro-pulse, the repetition rate is 100 Hz and travels in the same machine cycle as the H^+ beam through 100-MeV.

The existing 750 keV LEBT takes two beam species: H^+ and H^- , out of the 750 kV Cockcroft Walton (CW) generators and uses a combination of a beam chopper and radiofrequency cavities to produce this diverse set of beams. Two 201.25 MHz buncher cavities help accumulate dc beam into the phase acceptance of the DTL, and a 16.77 MHz cavity helps create the high-intensity pulse for Target 4. LANSCE has been in operations since 1972 and critical components are aging systems that are becoming hard to maintain due to lost expertise or simply lack of spares that are no longer fabricated. To maintain the unique capabilities of LANSCE in years to come, the LANSCE Accelerator Modernization Project (LAMP) plans to modernize the facility critical components [2]: replacing the two CWs

with a single RFQ, the new standard for ion beam facilities, and installing a new 100 MeV DTL. The new front-end must match into the existing facilities at the end of the DTL. With these configuration changes, the new LAMP front-end is required to produce each of the beams that are currently delivered to target areas. This paper describes the state of the physics design and model of the LAMP front-end and how it meets some of the most critical beam parameters at the end of the front-end concept.

PHYSICS MODEL

To model the new LAMP front-end, we have adopted a suite of accelerator codes that have been widely benchmarked by the community. Individual codes are selected to better capture the dynamics of individual sections of the front-end, but the same particle distributions are propagated through all the codes. In the design phase, we use the envelope codes Trace2D [3] and Trace3D [4] to design the low-energy beam transport (LEBT) and medium-energy beam transport (MEBT) lines. PARMTEQ-m [5] is used to design the RFQ, and PAR-MILA [6] is used to design the DTL, all LANL codes. Trace has proven to be particularly useful in finding compromised solutions to magnet settings that enable the transport of multiple beams.

For simulations with particles, the H^+ and H^- ion injectors are modelled in Warp [7] using available mechanical drawings. The LEBT simulation is done in Impact-t [8] and PARMILA, where Impact-t was first used to determine the required pulse length that preserves the high-current at the center of the pulse when producing the Target 4 beam, and then PARMILA calculates the dynamics at the center of the pulse. The RFQ vein geometry is exported to CST Particle Studio [9] for PIC simulations. The MEBT and DTL are also modelled in PARMILA. Multiple handovers of particle distributions are required when interfacing different codes, these are handled via Python scripts. Below we will describe each section of the front-end using the Target 4 beam as an example.

Injector Systems

The LAMP front-end assumes two 65 keV ion sources: one for H^+ beam and one for H^- beam. The beam physics modelling of the H^+ extraction electrodes is based on the LEDA injector that was in operation at LANL [10]. The H^- ion source is based on the SNS H^- source [11], with modifications to the electrostatic LEBT. This change is motivated by the extraction of dual H^- beam currents out of the

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same injector. Recent tests at SNS show extraction of 16 mA and 55 mA beam out of their source test stand [12]. In addition, by adjusting the Einzel lens voltage between pulses, control of Twiss parameters at the exit of the injector facilitates the simultaneous match of the two beam currents into the RFQ. Figure 1 shows the H^- injector model in WARP with extraction of Target 4, 55 mA beam and the associated electrode voltages.

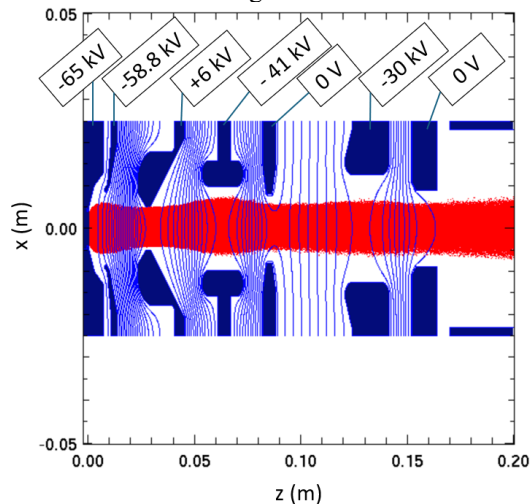


Figure 1: H^- injector system producing 55 mA beam. Red dots represent the macroparticles and blue equipotential lines are shown.

Low Energy Beam Transport

The LEBT is designed to transport both H^+ and H^- beams from the injectors and to simultaneously match them into the RFQ. It is formed by two independent beamlines that merge at a 15° angle with respect to the RFQ axis. Figure 2 shows a preliminary mechanical layout of this LEBT concept.

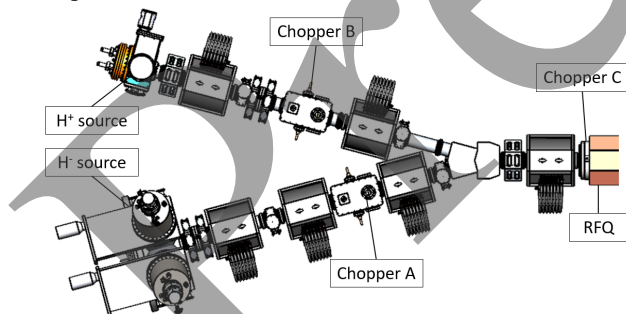


Figure 2: The 65 keV low energy beam transport concept with solenoids and choppers for LAMP.

The transverse focusing is done with solenoid magnets. Three electrostatic beam choppers are present in the LEBT: chopper A in the H^- beamline, chopper B in the H^+ beamline, and chopper C in the common beamline, just before the RFQ entrance. By using a combination of these three choppers, our present design can generate the temporal patterns required by the experimental targets. To produce the high intensity bunch to target 4, for example, chopper A lets through a 100 ns pulse every $1.8 \mu s$ for the duration of the macro-pulse. This pulse travels to the RFQ and expands

longitudinally due to significant space charge forces at 65 keV. We used Impact-t to determine the effect of pulse length at chopper A on the available current at the center of the pulse at the center of the RFQ entrance: for a 100-ns pulse generated at chopper A, the current at the center of the pulse at the RFQ entrance is reduced by a factor 0.97, thus we use PARMILA as a reasonable approximation of a pseudo-dc beam at the center of the pulse, Figure 3 shows the rms envelope of Target 4 beam through the LEBT in PARMILA.

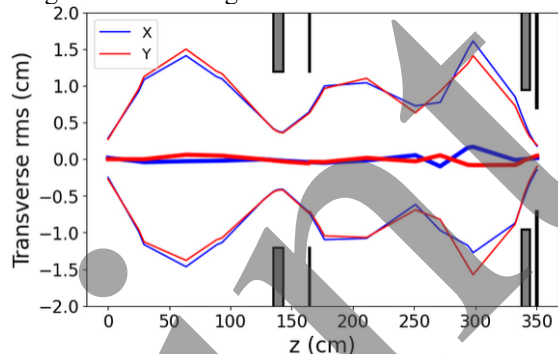


Figure 3: Horizontal and vertical rms beam envelopes of Target 4 beam in the LEBT simulation with PARMILA.

Chopper C is then used to only allow a shorter <50 ns pulse into the RFQ. Pulse lengths are mostly driven by the rise and fall times of the electrostatic choppers. Figure 4 shows the rms envelope near the RFQ entrance when the chopper C voltage is turned off and on. Chopper B is used to interrupt H^+ beam when chopper C is deflecting H^- beam.

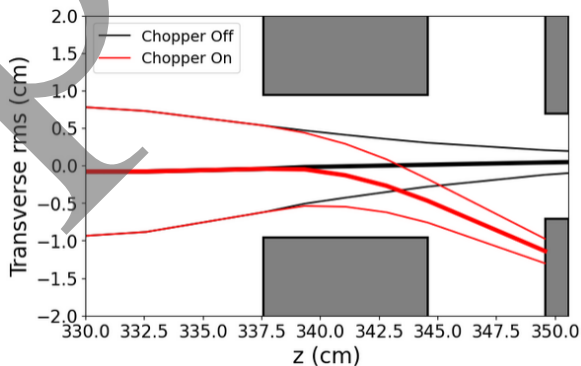


Figure 4: The vertical rms beam envelope upstream of the RFQ entrance showing the chopper C on and off.

Radiofrequency Quadrupole

The RFQ is a 201.25 MHz copper structure that takes both H^+ and H^- beams from 65 keV to 2.1 MeV. It is widely used as the new standard buncher and low energy accelerator at numerous ion beam facilities. The RFQ delivers a well-defined train of 201.25 MHz bunches. A 50 ns input pulse results in an output train 11-12 bunches. The Target 4 beam pattern requires a single bunch every $1.8 \mu s$. These satellites need to be removed by the MEBT choppers to meet the Target 4 requirement on dark current at target.

Medium Energy Beam Transport

The MEBT is designed to transport the beam from the RFQ to the DTL, it provides space for two traveling wave,

fast choppers [13]. The MEBT has quadrupoles for transverse focusing and re-buncher cavities for longitudinal focusing, a preliminary mechanical layout of the MEBT is shown in Figure 5.

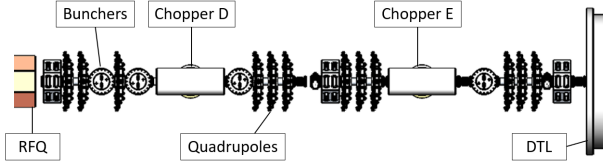


Figure 5: The 2.1 MeV medium energy beam transport concept for LAMP with two choppers.

Figure 6 shows the transverse and longitudinal beam rms envelopes for Target 4 beam through the MEBT.

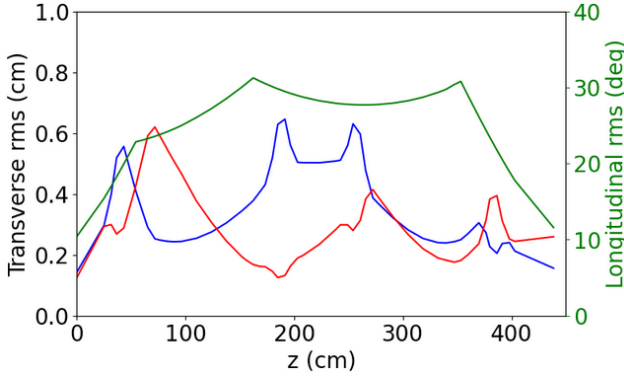


Figure 6: Transverse and longitudinal beam rms envelopes through the MEBT calculated with PARMILA.

The fast choppers are required to clean any tails on the beam patterns, and particularly to remove undesired satellite bunches produced by the RFQ when producing Target 4 beam [14]. Significant effort in the LAMP front-end design comes from a strict requirement on dark current intensity for Target 4 experiments: the ratio of intensity of the main bunch to intensity of satellites or dark current needs to be smaller than 10^{-5} . Figure 7 shows the vertical centroid and rms envelopes when the fast choppers are on and off.

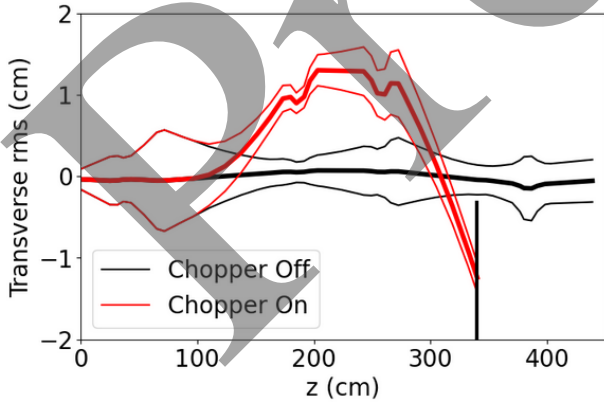


Figure 7: PARMILA simulation of Target 4 through the MEBT with chopper on and off.

Drift Tube Linac

The DTL is a normal-conducting, 201.25 MHz structure designed to accelerate all beams from 2.1 MeV to 100 MeV, it is designed with permanent magnet quadrupoles housed inside the DTL drift tubes for transverse

focusing. The design and simulation are done with PARMILA [15]. Figure 8 shows the transverse and longitudinal rms envelopes of Target 4 bunch through the DTL.

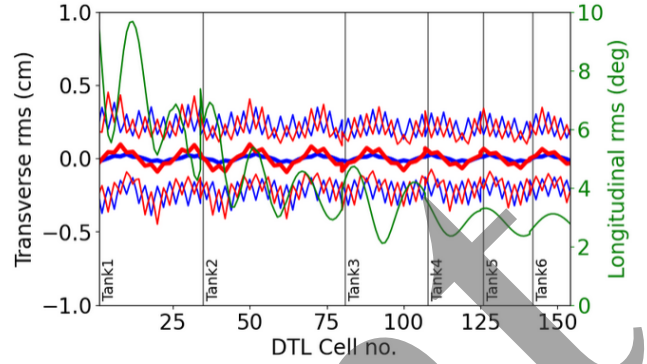


Figure 8: Transverse and longitudinal beam rms envelopes through the DTL calculated with PARMILA.

CONCLUSION

This paper discusses the current state of the physics design and simulations for the LAMP front-end. A multi-code approach is adopted to model the beam dynamics through the front-end main sections: injectors, LEPT, RFQ, MEBT and DTL. The corresponding particles distributions from each flavor are propagated from injector to the end of the DTL. Preliminary mechanical layouts have been generated to identify and resolve potential interferences in the designs. Table 1 summarizes the simulation results for IPF, Lujan and Target 4 beams at the end of the front-end and show that the project requirements on intensity and transverse emittance are met with the current design and provide sufficient overhead for more realistic simulations that include for example errors and tolerances into account [16].

Table 1: LAMP Beam Parameters at 100 MeV

Parameter	IPF	Lujan	Target 4
Beam energy [MeV]	100	100	100
Charge [pC]	58.98	76.18	212.60
Charge required [pC]	25	53	128
Current [mA]	11.87	15.33	42.78
Current required [mA]	5.2	10.5	25.6
Norm. rms emittance [π mm mrad]	0.346	0.448	0.683

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