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START-TO-END SIMULATIONS OF THE LAMP ACCELERATOR FRONT-END*

S. Sosa Guitron†, E. Henestroza, D. Gorelov, S. Kurennoy, J. Upadhyay, J.W. Lewellen, J. Barraza, K. Bishofberger, G. Dale, D.A. Dimitrov, Los Alamos National Laboratory, Los Alamos, NM 87545, USA

Abstract

The Los Alamos Neutron Science Center (LANSCE) accelerator delivers high intensity proton beams for fundamental science and national security applications since 1972. LANSCE is capable of simultaneous H^+ and H^- beam operations to multiple experiments requiring different time structures. This is achieved upstream in the facility with a combination of two 750 kV Cockcroft-Walton (CW) generators, a chopper and radiofrequency cavities, before going into the 800-MeV linac. The proposed LANSCE Modernization Project (LAMP) is evaluating critical machine upgrades necessary for continuous beam operations in decades to come. A significant component of LAMP is replacing the two CW with a dual-species 3-MeV Radiofrequency Quadrupole (RFQ). This change requires a full redesign of the LANSCE front-end accelerator to deliver the existing and expanded capabilities of the facility. This contribution will discuss the LAMP front-end accelerator layout based on the general beam requirements and on standard accelerator codes, showcasing the start-to-end propagation of H^+ and H^- beams from the source to the linac entrance.

INTRODUCTION

The LANSCE accelerator facility at the Los Alamos National Laboratory (LANL) is crucial at delivering high-intensity beams for multiple nuclear and neutron experiments: H^+ beam is delivered to the Isotope Production Facility (IPF), two H^- beams with different timing structures are delivered to the Lujan Center and to the Weapons Neutron Research (WNR) target, trains of H^- bunches are also delivered for proton-Radiography (p-RAD) and Ultracold Neutron (UCN) experiments.

The aging LANSCE infrastructure and lack of critical component spares require ever more challenging maintenance periods for continuous facility operations. This motivates the need for critical upgrades to maintain and expand the unique capabilities that LANSCE provides in years to come [1]. Some upgrades encompassed in the LANSCE Modernization Project (LAMP) are:

- New 100-keV, H^+ and H^- sources that enable beam operations at 35 mA, double the current.
- A new dual-beam Radiofrequency Quadrupole (RFQ) that replaces the two 750-keV Cockcroft-Walton (CW) generators.
- A new 201.25-MHz, 100-MeV Drift Tube Linac (DTL).

These upgrades require a complete re-design of the existing accelerator front-end. The LAMP study group is developing a new front-end layout to satisfy the LAMP requirements. In particular, the front-end design should produce the H^- beams that are routinely delivered to the Lujan Center and to WNR.

The Lujan beam is injected and accumulated in the Proton Storage Ring (PSR), it is formed by rf bunches separated by 5 ns for a duration of 270 ns, and a gap of no beam for 90 ns. This pattern repeats itself for the duration of a full 625 μs macro-pulse, effectively compressing a full macro-pulse into a single, high-intensity beam pulse that is delivered to the experimental target. The beam to WNR is formed from a sequence of 201.25 MH-z bunches separated every 1.8 μs over a 625 μs macro-pulse. This interbunch separation enables time-of-flight neutron studies, and care is taken to minimize beam dark current present in these gaps.

FRONT-END COMPONENTS

The LAMP front-end concept described in this paper is comprised of the following sections [2]:

- H^- and H^+ ion sources
- H^- and H^+ Low Energy Beam Transport (LEBT)
- Radiofrequency quadrupole
- Medium Energy Beam Transport (MEBT)
- Drift Tube Linac

A diagram of a LAMP front-end layout discussed in this paper is shown in Figure 1.

Sources

The H^+ and H^- beams are first produced at the 100 keV ion sources. Figure 2 shows both H^+ and H^- ion source models with electrode configurations, and the corresponding extracted beams. The model of the H^- source includes the dipole source in charge of deflecting the co-extracted electrons [3].

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† salvador@lanl.gov

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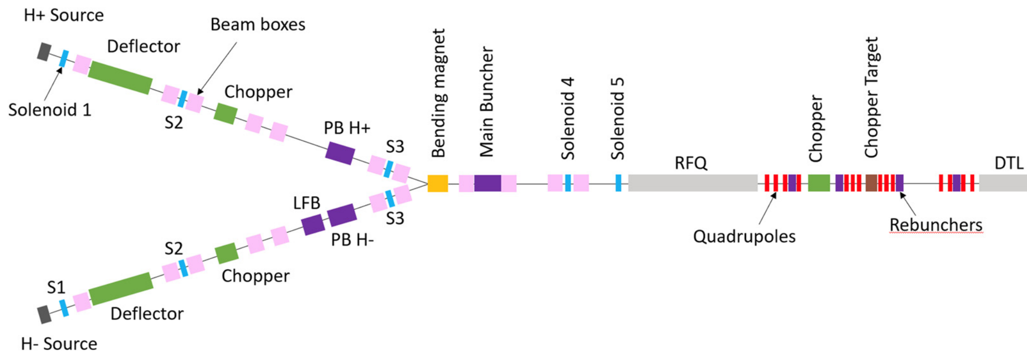

Figure 1: General layout of a LAMP front-end concept with H- and H+ beamlines merging at 9° angle. Solenoids in the LEBT provide matching to the RFQ. A MEBT is also used to transport and match between the RFQ and the new DTL.

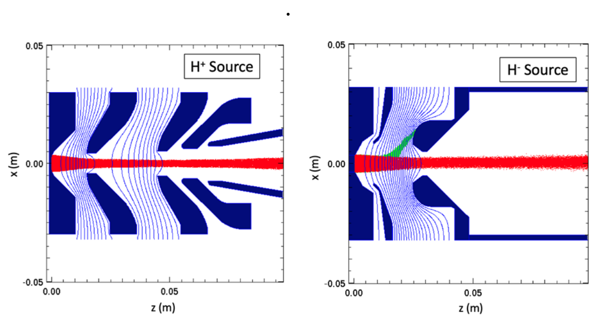

Figure 2: Warp models of 100-keV H+ ion source (left) and H- ion source (right). Electrodes are shown in solid blue, together with equipotential lines. Ion beams are red and electron beam is green.

Low-Energy Beam Transport

Two almost identical beamlines transport the 100-keV H+ and H- beams from the source to the entrance of the RFQ. The purpose of the LEBT is multi-fold: it provides transverse focusing and matching with a series of solenoid magnets, it provides room for beam diagnostics and for generating the beam time structure. The two lines merge via a 9° bending magnet. Beam diagnostics, such as emittance slits, collectors, and harps, are all placed in beam boxes, which are assumed to have dimensions equal to the existing beam boxes at LANSCE. The LEBT chopper [4] helps produce the required time pattern for the Lujan and WNR beams. A low frequency buncher is used to increase the charge per pulse for the WNR beam [5].

Radiofrequency Quadrupole

The proposed RFQ is a 3-MeV, 201.25-MHz accelerator designed for 35 mA beam current. It is a 5-m long structure, capable of accelerating individual beams to 3-MeV and producing symmetric matching of H+ and H- beams into the MEBT. By replacing both CW, the RFQ will need to be specially designed and optimized for dual-beam (H+ and H-), simultaneous operation. This technology has yet to be demonstrated and an RFQ Test Stand technology demonstrator is currently being built at LANL with this goal [6].

Medium-Energy Beam Transport

The MEBT transports the H+ and H- beams from the exit of the RFQ to the entrance of the DTL. The transport channel is based on the SNS MEBT [7] quadrupole lattice for transverse focusing, and on four double quarter-wave rebuncher cavities [8] for longitudinal focusing.

The MEBT also includes a 3-MeV fast chopper [4], a rise and fall time of 2 ns is required to remove the satellite bunches of the WNR beam produced in the RFQ [9]. These satellite bunches will show up as dark current in the WNR target. A 3-MeV beam collector is also required to capture the chopped beam.

Drift Tube Linac

The front-end includes the design and construction of a new 100-MeV, 201.25-MHz DTL. The new DTL is composed of 6 tanks and has an overall length of 50.3 m, For comparison, the existing LANSCE DTL has 4 tanks and total length 61.7m. The new DTL is being modeled in Parmila and leverages elements from SNS [7] and LANL existing DTL [10]. Figure 3 shows representative cells of the new DTL modeled in Superfish.

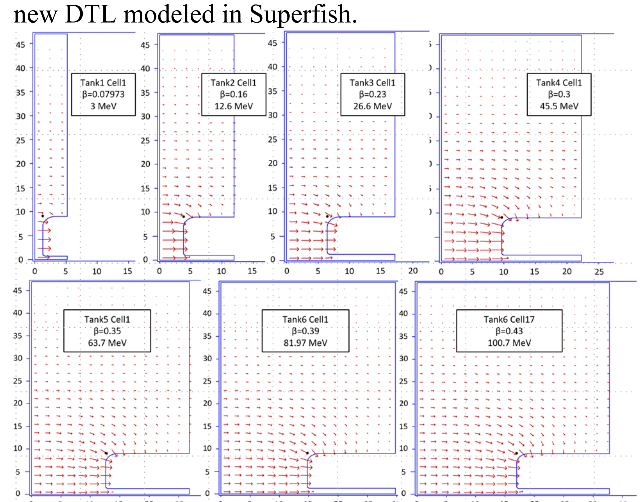

Figure 3: DTL reference cells modeled in Superfish. Electric field represented with arrow map.

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Table 1. Simulation Results for H^+ Beam to IPF

	Source	LEBT	RFQ	MEBT	DTL
Avg. Current [mA]	35	35	34.06	34.06	31.1
Bunch charge [pC]	DC beam	DC beam	170.3	170.3	155.6
Bunch length, rms [mm]	DC beam	DC beam	4	2.4	2.8
Transmission	100%	100%	97.50%	100%	91.40%
Norm. rms emittance (x/y) [mm.mrad]	0.08	0.08	0.21 / 0.22	0.32 / 0.35	0.6 / 0.7
Trans. Size rms (x/y) [mm]	1.8 / 1.8	0.75 / 0.75	0.79 / 0.76	1.76 / 1.79	1.05 / 3.6
z location [m]	1.18	9.02	14.4	18.04	68.9

Table 2. Simulation Results for H^- Beam to Lujan

	Source	LEBT	RFQ	MEBT	DTL
Avg. Current [mA]	35	35	34.06	34.06	31
Bunch charge [pC]	DC beam	DC beam	170.3	170.3	154.83
Bunch length, rms [mm]	DC beam	DC beam	4	2.6	2.9
Transmission	100%	100%	97.50%	100%	90.90%
Norm. rms emittance (x/y) [mm.mrad]	0.08	0.08	0.21 / 0.22	0.33 / 0.35	0.78 / 0.71
Trans. Size rms (x/y) [mm]	1.8 / 1.8	0.75 / 0.75	0.79 / 0.76	1.28 / 2.5	3.6 / 1.01
z location [m]	1.18	9.02	14.4	18.04	68.9

FRONT-END SIMULATIONS

With the goal of developing a consistent front-end layout capable of producing the most critical facility beams, we developed a modular, multi-code framework [2], summarized in Figure 4, that allows us to study and evaluate the beam dynamics of possible LAMP front-end configurations.

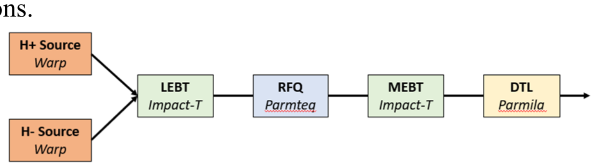

Figure 4: Multi-code framework of front-end sections for scoping studies of potential designs.

Both H^+ and H^- are simulated in Warp [11]. The beam transport through the LEBT is modelled in Impact [12], where field maps are used for the solenoids, the bending magnet and the low-frequency buncher. Pre-buncher and main buncher are also included in the model but are disabled from the simulations. The RFQ is modelled in standard RFQ design code Parmteq [13]. The MEBT is also modelled in Impact, and the DTL in Parmila [14]. The chopper fields are not included in this model. Interfaces between codes are performed using Python scripts. Results from simulations corresponding to H^+ and H^- beam to Lujan are summarized in Tables 1 and 2, where relevant beam parameters are reported at the end of each accelerator structure, or transport section.

CONCLUSION

We have established a multi-code framework to study the beam dynamics resulting from a particular front-end configuration. We developed this method to model the beam dynamics of a LAMP front-end capable of delivering H^+ and H^- Lujan beams. WNR beam generation using this layout remains to be done or will likely require significant changes to the design. The RFQ must be optimized for the WNR beam: with the low-frequency buncher, this pulse has more than 100 mA peak current, which results in significant losses for conventional RFQ designed to accept 35 mA of DC beam. The use of the pre-buncher and main buncher cavities was initially inherited from LANSCE, but they may not be required since the RFQ is itself a beam buncher. These elements were included in this model but disabled from the simulation. Both the RFQ and DTL are being optimized for improved matching and reduced emittance grow.

BIBLIOGRAPHY

[1] Y. Batygin, D. Gorelov, S. Kurennoy, J. Lewellen, N. Moody. “LANSCE Front-End Upgrade: Preconceptual Design Study”, LANL Internal Report, LA-UR-20-24199, June 2020.

[2] S. Sosa Guitron, D. V. Gorelov, S. S. Kurennoy, J. Upadhyay, E. Henestroza, “Start-to-end simulation for LAMP front-end scoping studies”, LA-UR-2421709, February 2024.

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPC30

[3] T. Kalvas, R. F. Welton, O. Tarvainen, B. X. Han, M. P. Stockli, “Simulation of H- ion source extraction systems for the Spallation Neutron Source with Ion Beam Simulator”, Rev. Sci. Instrum. 83, 02A705, 2012.

[4] S. Kurennoy, “Fast Beam Choppers for a New LANSCE Front End: Preliminary Modeling Results”, LA-UR-23-23852, 2023.

[5] S. Kurennoy, “CST Model of Low Frequency Buncher”, AOT-AE 24-001 (TN), LANL technical note, January 2024.

[6] R. T. Thornton, *et al*., “Initial Results from 35 keV H+ beam at the LANL RFQ Test Stand,” presented at IPAC’24, Nashville, TN, USA, May 2024, paper MOPC39, this conference.

[7] S. Henderson *et al*., “The Spallation Neutron Source accelerator system design”, in NIM-A 763, pp. 610-673, 2014.

[8] S. Kurennoy, “Quarter-wave buncher cavity for the new front end of the LANSCE”, AOT-ABS 08-001 (TN), LANL memorandum, January 2008.

[9] Y. K. Batygin, D. A. D. Dimitrov, I. Dragani, D. V. Gorelov, E. Henestroza, and S. S. Kurennoy, “High-Brightness RFQ Injector for LANSCE Multi-Beam Operation”, in *Proc. LINAC'22*, Liverpool, UK, Aug.-Sep. 2022, pp. 130-133. doi:10.18429/JACoW-LINAC2022-MOPOPA24

[10] T. P. Wangler, *RF Linear Accelerators*, 2nd Ed., Wiley-VCH, 2008.

[11] WARP, http://warp.lbl.gov

[12] J. Qiang, S. Lidia, R. D. Ryne, C. Limborg-Deprey, Phys. Rev. Special Topics – Accel. Beams 9, 044204, 2006.

[13] K. R. Crandall *et al*., “RFQ Design Codes”, LA-UR-96-1836, Revised December 7, 2005.

[14] H. Takeda and J. H. Billen, “Recent Developments in the Accelerator Design Code PARMILA”, in *Proc. LINAC'98*, Chicago, IL, USA, Aug. 1998, paper MO4047, pp. 156-158.