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

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Abstract

The LANSCE Accelerator Modernization Project (LAMP) plans to replace the two existing 750-keV Cockcroft Waltons by a single radio-frequency quadrupole (RFQ), and to install a new 100-MeV drift-tube linac (DTL). LAMP will simultaneously produce H^+ and H^- beams with different timing patterns to serve multiple experimental facilities. A low energy beam transport (LEBT) is designed to transport H^+ and H^- beams from the ion sources into the 201.25 MHz RFQ, where the beams accelerate to 3 MeV. A medium energy beam transport (MEBT) is designed to transport the beam from the RFQ to the DTL. The DTL accelerates both beams to 100 MeV. The LEBT and MEBT designs include beam choppers and rf systems that imprint the multiple timing patterns required by experiments. Here we describe a concept of the LAMP front-end and present particle simulation results for multiple beams relevant to the facility.

INTRODUCTION

The LANSCE accelerator facility at LANL plays a crucial role in delivering high-intensity proton and neutron beams for a wide range of experiments with different intensity and time patterns. To maintain these LANL capabilities in the future, the LANSCE Accelerator Modernization Project (LAMP) plans to upgrade the LANSCE front-end by replacing the two 750-keV Cockcroft-Walton generators for a single, dual-species 3 MeV RFQ, and replacing the existing 100-MeV DTL [1]. These upgrades require a complete re-design of the front-end to accommodate for these major systems.

LANSCE is a pulsed accelerator with a 1-ms cycle. Different beams are produced and delivered during each machine cycle, usually a macro-pulse that is 625 µs long. Each beam has a different time structure [2]. Here we describe three beams, identified by their corresponding experimental target: the Lujan Center, the Weapons Neutron Research (WNR) and the Isotope Production Facility (IPF). The Lujan beam is the H^- beam used for accumulation in the Proton Storage Ring (PSR), it is formed by trains of 201.25 MHz rf bunches and is 270 ns long, this is a mini-pulse. Mini-pulses are separated by a 90 ns gap, necessary for PSR injection and extraction kickers to ramp-up. The beam repetition rate is 20 Hz. The WNR beam consists of high-intensity H^- bunches separated every 1.8 µs over the length of the macro-pulse. An empty gap between micro-pulses is required for accurate neutron time-of-flight studies. The beam repetition rate is 100 Hz. The IPF beam consists of H^+ rf bunches separated every 5 ns over the macro-pulse. The beam repetition rate is 100 Hz. The WNR and IPF beams share the same machine cycle, which means they are produced and transported at the same time. Single-shot beams are also delivered to proton-Radiography (pRad) and the Ultra-Cold Neutron (UCN) experiments. The new LAMP front-end design should be able to produce all the beams that LANSCE currently delivers.

A significant change is that LANSCE forms all beam patterns in the 750-keV LEBT. In the new front-end, all beams now need to be formed in the 100-keV LEBT and the 3-MeV MEBT [3]. In particular, the LEBT has significantly higher space charge forces acting on the beams, particularly in the WNR high-intensity beam.

We will describe design considerations on the transport lines and discuss start-to-end simulation results showing how the present design meets beam intensity require-ments for LAMP.

Low-Energy Beam Transport

A LEBT concept was designed to transport multiple beams from the ion sources to the RFQ. Figure 1 shows the layout of the LAMP LEBT. The Lujan and IPF beams are long pulses, and we expect a high degree of space charge neutralization, assumed 90%, can be achieved [4] from interaction with the background gas. For the WNR beam, the LEBT chopper produces an initial short pulse, 25-ns, that is spaced every 1.8 µs. No space charge neutralization can be assumed in this case.

The initial chopped pulse for WNR is compressed using a 16.77 MHz buncher [5] to increase the charge at the central 5-ns of the pulse, this high-intensity bunch formation scheme produces satellite bunches that need to be removed in the MEBT [6]. Under these conditions, together with the high-charge per pulse requirement at the WNR target, the LEBT is designed to maximize the transmission of the 35-mA short pulse for WNR beam. The WNR beam then sets the magnet settings on most of the LEBT magnets. The RFQ matched beam parameters are calculated for the Lujan and the IPF beams, and backpropagated through the LEBT. The independent Lujan and IPF beamlines provide sufficient variables to match the beams at the merging locations. The IPF beam merges at a 9° magnet, and the Lujan beam gets kicked into the WNR line upstream of the chopper.

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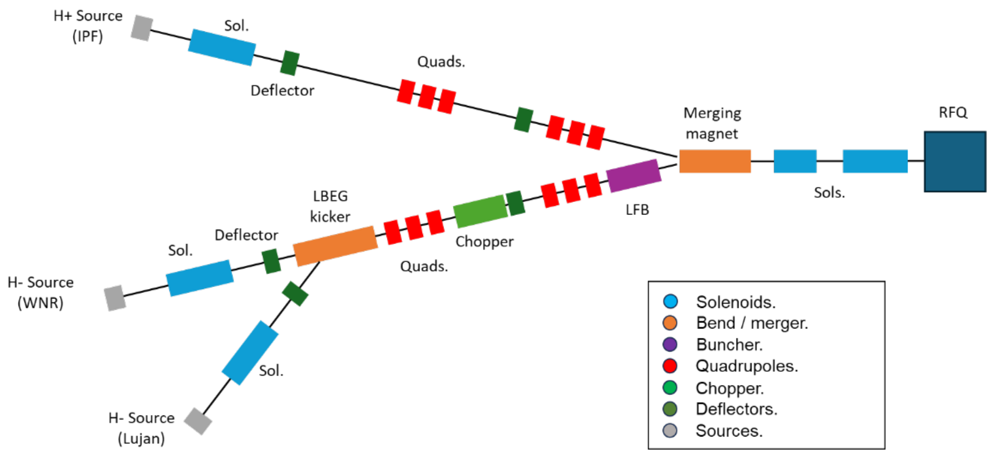

Figure 1: A layout of the of LAMP LEBT concept design, with multiple beam transport lines and designed for simultaneous match into single RFQ.

Medium-Energy Beam Transport

The LAMP 3-MeV MEBT is designed to transport all beams from the RFQ to the DTL. The MEBT uses quadrupoles and re-bunchers to transport and match the beams into the DTL. The MEBT also adopts a two-chopper scheme [6]. Fast-choppers with 2-ns rise and fall time are required to remove the satellite bunches of the WNR beam [5]. The fast rise time limits the available voltage that can be delivered to the chopper plates, and therefore a two-chopper scheme is implemented that provides sufficiently large deflection to remove the satellites. The requirement on satellite intensity after the MEBT choppers is set up by the WNR requirement on dark current, this is 10^{-5} smaller than the intensity of the main bunch.

START-TO-END SIMULATIONS

We implement a multi-code simulation framework, where different codes are used that better capture the beam dynamics in each of the LAMP front-end sections. The LEBT and MEBT are designed using Trace 2D [7] and Trace 3D [8].

The H^+ and H^- beams are first produced in a model of the ion sources in Warp [9], and the same distribution of particles will be propagated through the rest of the front-end model. The beam transport through the LEBT is modelled in PARMILA [10] and Impact-t [11], where PARMILA is used for long pulses, and Impact-t is used for modelling the WNR pulse formation with the chopper and low frequency buncher. The RFQ is first designed in PARMTEQ-m [12] and then exported into CST Particle Studio [13] for PIC simulations. The MEBT and DTL are also modelled in PARMILA. Handovers of particles between codes are implemented as Python scripts. Figure 2 illustrates our multi-code simulation framework to develop and evaluate the LAMP front-end design.

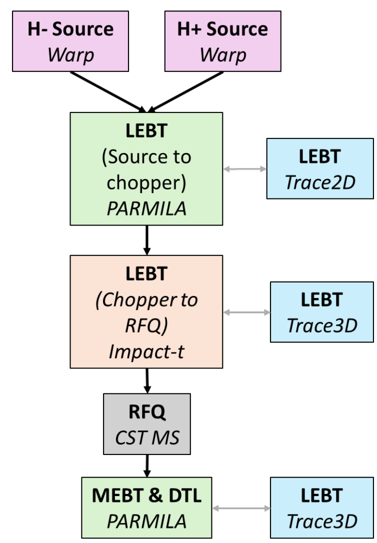

Figure 2: Simulation framework for LAMP front-end.

Simulation results

Table 1 provides detailed performance and beam parameters at the beginning of each front-end section. In the LEBT and RFQ columns, the charge and current are listed based on the central 5 ns portion of the pulse. Notably, we can see the effect of the low frequency buncher in increasing the charge at the central pulse by at least a factor of two. We calculate the transmission through the RFQ based on charge collected in the central 5-ns section of the pulse going in, and the highest charge bunch coming out. The rows showing charge required and current required list the estimated minimum threshold for the LAMP requirements to be met at the WNR target. Our present front-end design delivers the project requirements and provides some overhead for more detailed simulations. Table 2 shows an equivalent summary for the IPF and Lujan beams at the DTL entrance.

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Table 1: Simulation Results for Beam to WNR

	LEBT	RFQ	MEBT	DTL
z location [m]	0.15	4.749	10.149	14.536
Beam energy [MeV]	0.1	0.1	3	3
Transmission [%]	100	92.9	53	89.95
Charge [pC]	174	391.3	206.8	186.01
Charge required [pC]	152	254	178	160
Current [mA]	35.1	78.7	41.62	37.44
Current required [mA]	30.5	50.8	35.6	32
Emittance (x/y) N,rms [π cm mrad]	0.013/ 0.009	0.069/ 0.080	0.0743/ 0.0716	0.087/ 0.071
Long. Emittance rms [π deg MeV]	-	-	0.233	0.403

Table 2: Simulation Results for IPF and Lujan Beams

	H^+(IPF)	H^-(Lujan)
z location [m]	14.536	14.536
Beam energy [MeV]	3	3
Transmission [%]	91.8	98.5
Charge [pC]	54.7	79.33
Charge required [pC]	26	65.9
Current [mA]	11.01	15.96
Current required [mA]	5.3	13.2
Emittance (x/y) N,rms [π cm mrad]	0.023/ 0.018	0.031/ 0.033
Long. Emittance rms [π deg MeV]	0.22	0.297

CONCLUSION

We have designed a model of the new front-end for LAMP and used a multi-code simulation framework to estimate, among other beam properties, the charge per bunch for three widely different beams that need to be produced. Using known losses from LANSCE in the high-energy transport and the Linac, we backpropagate the project requirement on bunch intensity from the target to the front end and compare against the beam intensity produced by the model of the LAMP front-end at the different relevant sections. Our model successfully delivers the required charge per bunch at each section and provides some overhead for more detailed simulations. These results are reported in Tables 1 and 2. On-going studies include sensitivity analysis of critical components like choppers and low frequency buncher, misalignments and minimization of emittance growth.

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