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DESIGN OF A MULTI-PURPOSE LEBT FOR THE LANSCE FRONT END UPGRADE*

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Abstract

The Los Alamos Neutron Science Center (LANSCE) facility at LANL is considering an upgrade of its front end, from the source to the end of a 100 MeV Drift Tube Linac (DTL). One of the main features of LANSCE is that it delivers several types of bunching systems to five users (Isotope Production Facility, Lujan Neutron Scattering Center, Ultra Cold Neutron Center, Proton Radiography Facility "pRad" and the Weapons Neutron Research Facility "WNR"). The first three users accept bunch trains modulated at 201.25 MHz produced from quasi-DC beams. The WNR facility requires the delivery of sub-nanosecond bunches every 1.8 µs. At present the bunching system for the WNR beam is prepared in a 750 keV Low Energy Beam Transport (LEBT) lattice. The proposed upgrade will need to manipulate short bunches for WNR at an energy of 100 keV to be injected into a 3 MeV RFQ. The quasi-DC beams can be charge-compensated by the ionization of background gas, which cannot be done for the short bunches of WNR. A similar situation happens with the pRad beams. At such low beam energy, the uncompensated space charge of the bunch will require a special LEBT design that will work simultaneously for all types of beams to be delivered by the LANSCE upgrade. We will describe a new LEBT layout for the LANSCE Front End Upgrade that will be able to deliver the required beam bunches to all facilities.

INTRODUCTION

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 cavity pre bunchers, and a Drift Tube Linac to accelerate the beam to 100 MeV. 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 re-design of the LANSCE front-end accelerator to deliver the existing and expanded capabilities of the facility.

A design of a concept for a Front End Upgrade of the LANSCE Linac has been set up to perform a start-to-end modeling of the system at the current development stage. The components of the design are shown in Fig. 1. The sequence of the components is correct; however, the sketch is not to scale.

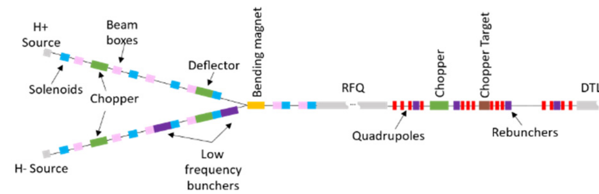

Figure 1. Concept for a LANSCE Front End Upgrade.

The LANSCE Upgrade front-end concept discussed here evolved from a design described in a previous report [1]; the H^- and H^+ ion sources, the RFQ and the MEBT have not changed. Here we will discuss the design of a multi-purpose LEBT that will work simultaneously for all types of beams to be delivered by the LANSCE upgrade.

CHARGE COMPENSATION IN THE LEBT

The LANSCE Front End Upgrade is required to deliver 625 µs beam macro pulses with specific time structures to the present users. A chopper located in the H- LEBT provides such bunching systems.

The use of a 100 keV beam to inject into the 3 MeV RFQ that replaces the Cockcroft-Walton generators turns the LANSCE 750 keV LEBT into a 100 keV LEBT, thereby increasing the space charge force substantially: $(750/100)^{1.5}$ ~20. Therefore, there is a large difference in the beam dynamics in the 100 keV LEBT among beam pulses that can or cannot be charge compensated.

To study the beam dynamics in the LEBT, we can group the five types of beam structures in two groups.

The macropulses delivered to Lujan Neutron Scattering Center, Ultra Cold Neutron Center and Isotope Production Facility can be treated as long (625 µs) quasi-DC beams where we expect to have in the 100 keV LEBT a large charge-compensation by ionization of the background gas [2]. This type of macropulses will be referred as **LBEG**-type beams. The H+ beam delivered to the Isotope Production Facility is a DC beam, but the other two H- beams are basically 625 µs pulses where 70 ns slices are removed every 360 ns.

The Weapons Neutron Research Facility requires the delivery of sub-nanosecond bunches every 1.8 µs at the target. At present the bunching system for the WNR beam is prepared in a 750 keV LEBT where the macropulse is chopped every 1.8 µs to provide a 30 ns beam bunch to a 16.67 MHz Low Frequency Buncher that compresses the pulse to ~ 5ns to match the frequency (201.25 MHz) of the 750 keV-100 MeV DTL. Due to the sparsity of this time

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structure, we do not expect that the background gas ionization could provide any charge compensation. This type of macropulses will be referred as **MPEG**-type beams. The beam to be delivered to the Proton Radiography Facility can also be considered an MPEG beam.

MULTI-PURPOSE LEBT

For the H- LEBT of the LANSCE Front End Upgrade to be able to generate and transport the LBEG and MPEG type of beams simultaneously, we have revised the LEBT design described in our previous report [1]. The major issue driving the design is the control of the 3D expansion of the short MPEG beam bunches due to the uncompensated space charge forces.

The layout of the new 4.8 meter LANSCE Upgrade LEBT for both species (H+ and H-) showing the location of the focusing elements (solenoids) and ancillary components is shown in Fig. 2. This LEBT is shorter than the previous design to reduce the distance for the transport of the MPEG beam without charge compensation. Included are two Low Frequency Buncher Cavities operating at 16.67 MHz to control the longitudinal dynamics of the MPEG beam.

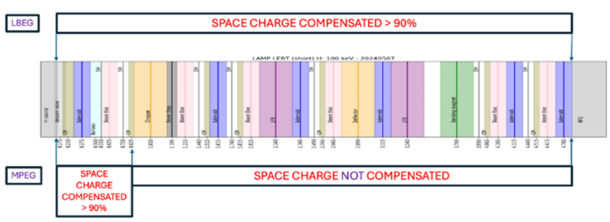

Figure 2. Layout of multi-purpose LEBT for LANSCE Front End Upgrade.

BEAM DYNAMICS SIMULATIONS

The end of the LEBT is at 4.82 meters measured from the beam aperture at the source Pierce electrode. It is also the location where the beam enters the RFQ. The beam dynamics calculations in the LEBT were performed using the beam bunch obtained from the WARP [3] source calculations [1]. The location of this initial bunch, at the chopper location, was chosen to separate the modeling of the two kinds of beam produced by the LANSCE Upgrade. For the LBEG beam we assume total space-charge compensation along the rest of the LEBT. For the MPEG beam there is no charge compensation after the macro-pulse is chopped.

The H+ DC beam and the quasi-DC H- LBEG beam transport in the LEBTs are modeled in IMPACT-T [4] using a 25 ns beam pulse (5-RF 201.25 MHz cycles) selected from the particle distributions as calculated by WARP from the source to the entrance to the chopper. This calculation assumes total charge compensation to prevent unphysical beam debunching of a DC beam.

The MPEG beam is modeled using a profiled 25 ns (7 rise + 11 flat + 7 fall) beam pulse (5-RF cycles) in IMPACT-T. The initial conditions are also obtained from the WARP calculation from the source to the entrance to the chopper. This pulse is compressed using two Low Frequency Bunchers. This bunch is used to propagate the MPEG beam through the RFQ. For this calculation there is no charge compensation. The two Low Frequency Bunchers are used to control the physical debunching of the beam due to the space-charge forces.

An acceptable LEBT design requires the delivery of the right number of particles at the exit of the DTL (100 MeV) for the LBEG and MPEG beams. Therefore, each iteration required the beam dynamics calculation from start (chopper location) to end (of DTL). We used IMPACT-T to model the beam dynamics in the LEBT, RFQ and MEBT. The DTL was modeled using the PARMILA code [5]. Note that the particle population that were obtained from the WARP source calculations were propagated from the start to the end of the simulation.

LBEG Beam

The x-RMS, y-RMS and z-RMS beam size of the H- LBEG beam in the LEBT and MEBT are shown in Figs. 3 and 6, respectively. Figures 4 and 5 show the phase space distribution at the exit of the LEBT and MEBT.

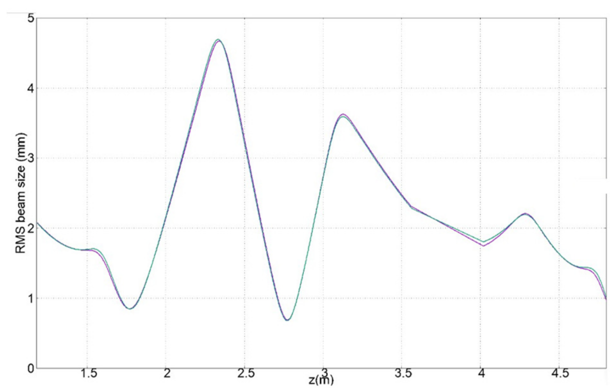

Figure 3. x-RMS and y-RMS beam size of the H- LBEG beam along the LANSCE Upgrade H- LEBT.

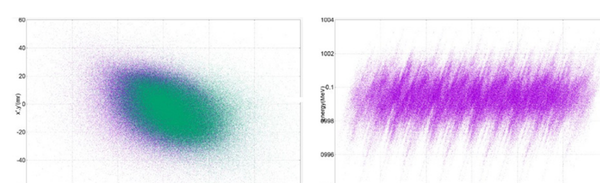

Figure 4. Particle phase space: horizontal and vertical (left) and longitudinal (right) of the H- LBEG beam at the exit of the LANSCE Upgrade H- LEBT.

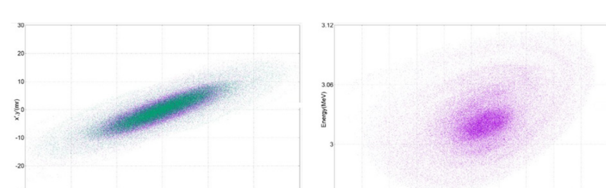

Figure 5. Particle phase space of a single bucket: horizontal and vertical (left) and longitudinal (right) of the H- LBEG beam at the exit of the RFQ.

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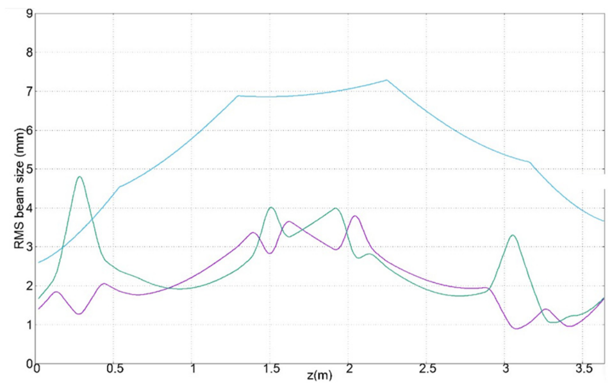

Figure 6. x-RMS, y-RMS and z-RMS beam size of the H- LBEG beam along the LANSCE Upgrade MEBT.

MPEG Beam

The x-RMS, y-RMS and z-RMS beam size of the H- MPEG beam in the LEBT and MEBT are shown in Figs. 7 and 10, respectively. Figures 8 and 9 show the phase space distribution at the exit of the LEBT and MEBT.

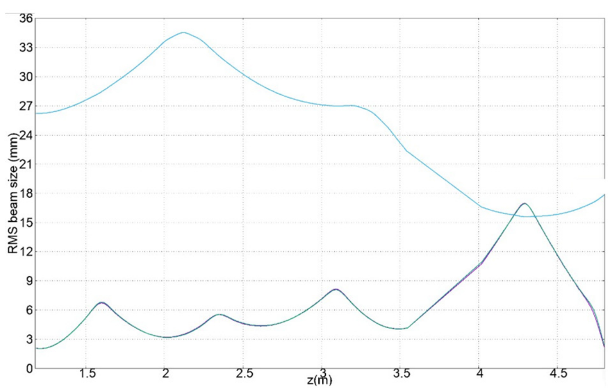

Figure 7. x-RMS, y-RMS and z-RMS beam size of the H- MPEG beam along the LANSCE Upgrade H- LEBT.

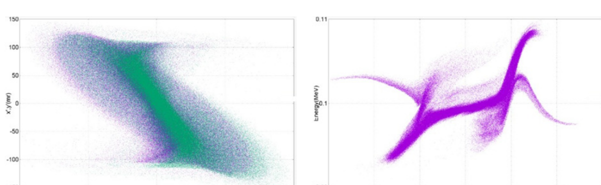

Figure 8. Particle phase space: horizontal and vertical (left) and longitudinal (right) of the H- MPEG beam at the exit of the LANSCE Upgrade H- LEBT.

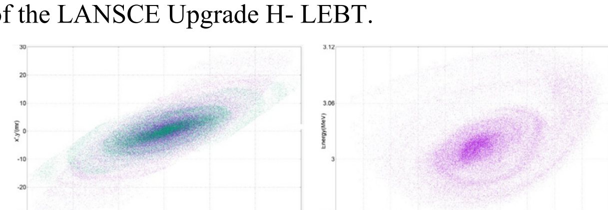

Figure 9. Particle phase space of a single bucket: horizontal and vertical (left) and longitudinal (right) of the H- MPEG beam at the exit of the RFQ.

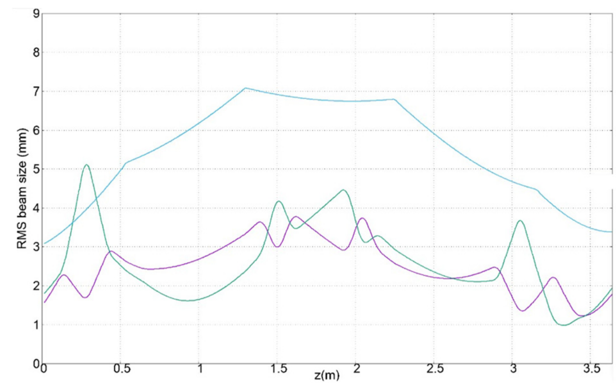

Figure 10. x-RMS, y-RMS and z-RMS beam size of the H- MPEG beam along the LANSCE Upgrade MEBT.

CONCLUSIONS

The corresponding particle phase space distributions at the exit of the MEBT were used by the PARMILA code [5] to push particles through a design of the LAMP DTL [6].

The final total charge of the particles in an RF bucket at the end of the DTL is 150, 155, and 110 pC for the H+, the H- LBEG and the H- MPEG beams respectively. Further matching [7] of the beams by adjusting parameters in the LEBT and MEBT would produce more particles transmitted through the DTL. Therefore, this design of a multi-purpose LEBT is expected to meet the objectives of the LANSCE Front End Upgrade project for all user facilities.

BIBLIOGRAPHY

[1] S. Sosa et al., "Start-to-end simulations of the LAMP accelerator front-end", in *Proc. IPAC'24*, Nashville, TN, May 2024, pp. 3049-3052. `doi:10.18429/JACoW-IPAC2024-THPC30`

[2] Y. K. Batygin, I. N. Draganic, C. M. Fortgang, and G. Rouleau, "Space Charge Neutralization of Low Energy H- Beam", in *Proc. IPAC'13*, Shanghai, China, May 2013, paper TUPWA066, pp. 1856-1858.

[3] WARP, `http://warp.lbl.gov`

[4] J J. Qiang, S. Lidia, R. D. Ryne, and C. Limborg-Deprey, "Three-dimensional quasistatic model for high brightness beam dynamics simulation," *Phys. Rev. Spec. Top. Accel Beams*, vol. 9, no. 4, p. 044204, Apr. 2006. `doi:10.1103/physrevstab.9.044204`

[5] 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.

[6] D. Gorelov *et al*., "DTL Studies for the LANSCE Future Front-End Upgrade at LANL", presented at LINAC'24, Chicago, IL, USA, Aug. 2024, paper MOPB083, this conference.

[7] L. Duffy, S. Sosa *et al*., "Beam envelope matching for the LANSCE Modernization Project", presented at. LINAC'24, Chicago, IL, USA, Aug. 2024, paper MOPB089, this conference.