

DESIGN AND OPTIMIZATION OF A 10.0625 MHz LOW-FREQUENCY BUNCHER FOR A 201.25 MHz RFQ ACCELERATOR*

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Abstract

The LANSCE Accelerator Modernization Project (LAMP) will replace the front-end of the existing LANSCE accelerator, from ion sources through the end of the 100-MeV drift-tube linac. The LAMP design includes injecting a bunched beam into an RFQ. The RFQ test stand (RFQTS) will demonstrate this technique using an existing RFQ. This paper discusses the design of the low frequency buncher for the RFQTS. CST simulations were used to study the effects of gap length, bunching voltage, and beam-pipe aperture on the transmission efficiency, transit-time factor, emittance growth, and bunching efficiency. The optimized LFB provides effective pre-bunching, while a downstream solenoid focuses the beam to minimize transverse emittance growth and ensure proper injection into the RFQ.

INTRODUCTION

The Los Alamos Neutron Science Center (LANSCE) accelerator facility uses two Cockcroft-Walton accelerators to produce H^- and H^+ beams for six end-user facilities [1]. The LANSCE Modernization Project (LAMP) plans to replace the aging Cockcroft-Waltons with a single Radio-Frequency Quadrupole (RFQ) [2]. This upgrade requires research and development to maintain the beam timing and parameters required by users.

To support LAMP development, an RFQ Test Stand (RFQTS) is under construction using an existing RFQ with an input energy of 35 keV and output energy of 750 keV [3]. The RFQ is a 4-rod structure manufactured by Kress GmbH [4,5].

The Weapons Neutron Research (WNR) facility at LANSCE requires high peak-current beam operation. At LANSCE, this is achieved using a Low-Frequency Buncher (LFB) to compress the H^- beam into 5 ns high-current bunches [6]. To reproduce similar beam conditions on the RFQTS, an LFB system is also required for the test stand.

This work presents the design and optimization of a 10.0625 MHz LFB for the RFQTS operating with a 35 keV, 15 mA proton beam. The buncher uses a two-gap beam-pipe structure with a center beam pipe driven by an RF voltage to longitudinally bunch the beam. Electrostatic and particle-in-cell (PIC) simulations were performed using CST Studio Suite [7] to evaluate bunching performance and RFQ transmission.

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LEBT OVERVIEW

The low-energy beam transport (LEBT) line for the RFQTS is shown in Fig. 1. For the simulations presented in this work, the ion source is assumed to produce a 35 keV, 15 mA ion beam. A chopper generates 150 ns beam pulses that are transported to the LFB, where the beam is modulated by RF electric fields. Downstream of the LFB, a solenoid with a peak B-field of 0.28 T focuses the beam before injection into the RFQ. The RFQ bunches and accelerates the beam to 750 keV. The component configuration considered in this work is based on continued development of the RFQTS LEBT design presented in [8].

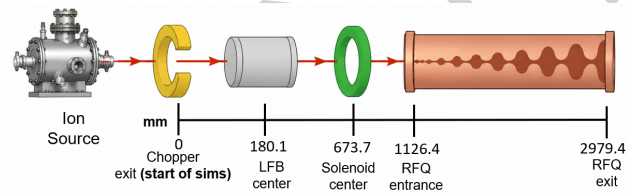


Figure 1: Simplified RFQTS LEBT layout showing the relative spacing of the ion source, chopper, LFB, solenoid, and RFQ.

LFB DESIGN

Figure 2 shows the LFB geometry and dimensions considered in this work. The outer diameter (OD) and gap sizes were varied in the simulations and do not represent final design values. The beam-pipe wall thickness was chosen to be 6.35 mm so the gap edges could be beveled to reduce electric-field enhancement. The structure consists of three beam-pipe sections enclosed by an outer tank, with the center section separated from the two grounded outer sections by two gaps. The center beam pipe is driven by an RF voltage that generates longitudinal electric fields across the gaps to modulate the beam energy.

The RF phase is chosen so the leading portion of the beam is decelerated while the trailing portion is accelerated, producing longitudinal bunching. The second gap reinforces this energy modulation and increases the bunching effect.

The two gaps are separated by a distance of $\beta\lambda/2$ to maintain the correct RF phase relationship. For a 35 keV proton beam operating at 10.0625 MHz, this corresponds to a gap-center spacing of 128.6 mm.

ELECTROSTATIC STUDIES

Electrostatic simulations of the LFB were performed to evaluate the electric-field distribution and transit-time factor (TTF) for varying gap sizes. A 1 kV DC voltage was applied

to the center beam pipe while the remaining structure was held at ground potential.

Figure 3(a) shows the longitudinal electric-field component along the beam axis for gap sizes ranging from 10 mm to 40 mm. Opposite field polarity is observed across the two gaps, and the peak electric-field magnitude decreases with increasing gap size. Figure 3(b) shows the longitudinal electric-field contour for the LFB. The maximum electric field near the gap edges is approximately 103 kV/m, and the calculated capacitance between the center and outer beam pipes is 12.7 pF.

The TTF was calculated for gap sizes ranging from 10 mm to 40 mm and beam-pipe ODs of 50.8 mm, 76.2 mm and 101.6 mm.

Figure 4 shows that the TTF decreases slightly with increasing gap size. The beam-pipe OD had a stronger effect on the TTF, with the 50.8 mm OD producing the highest values and the 101.6 mm OD producing the lowest.

PIC STUDIES

LFB PIC Results

PIC simulations were performed using the CST Studio Suite PIC solver from the chopper exit to the RFQ entrance, corresponding to the LEBT shown in Fig. 1. The beam was initialized using Twiss parameters derived from the RFQTS LEBT design reported in [8]. A 150 ns chopped beam pulse

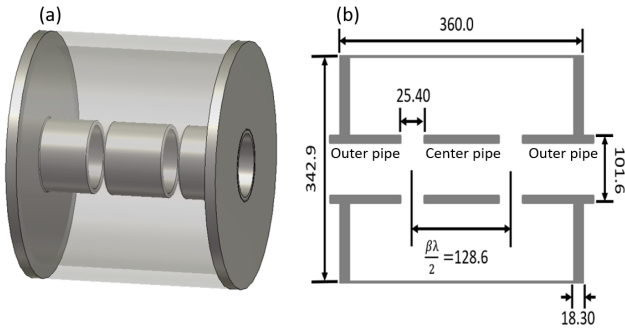


Figure 2: LFB geometry used in the simulations: (a) model of the LFB structure and (b) cross-section showing the main dimensions.

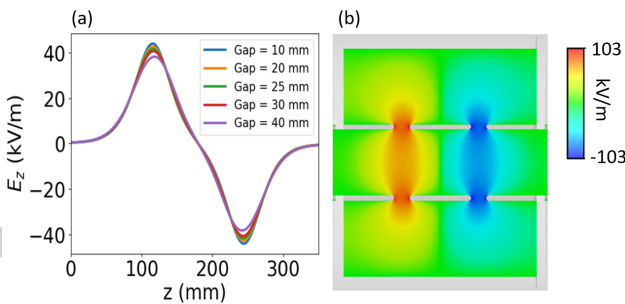


Figure 3: Electrostatic simulation results for the LFB. (a) Longitudinal electric-field component (E_z) along the beam axis for gap sizes ranging from 10 mm to 40 mm. (b) Cross-sectional contour plot of the longitudinal electric field for the LFB geometry shown in Fig. 2.

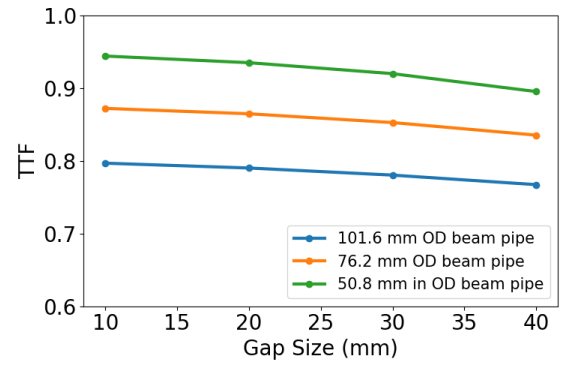


Figure 4: Calculated transit-time factor (TTF) as a function of gap size for three beam-pipe outer diameters.

was modeled using time-dependent macro-particle emission. RF electric fields derived from the electrostatic simulations and magnetic fields from the LEBT solenoid magnetostatic simulations were imported into the PIC model. The LFB phase was chosen such that the beam center arrived at the center of the first buncher gap.

Figure 5 shows the longitudinal evolution of the beam through the LEBT for a 3 kV bunching voltage, 25.4 mm gap size, and 101.6 mm beam-pipe OD.

Immediately downstream of the LFB, the beam exhibits the expected energy modulation, with the leading portion decelerated and the trailing portion accelerated by the RF electric fields. During transport through the LEBT, this

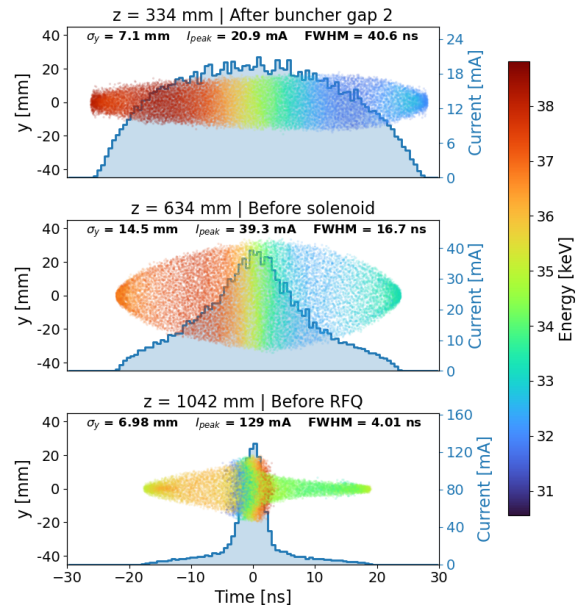


Figure 5: Evolution of the beam bunching process through the LEBT for a 3 kV LFB voltage, 25.4 mm gap size, and 101.6 mm beam-pipe OD. Particle distributions are colored by beam energy and overlaid with beam current profiles (blue histograms) at locations immediately after the LFB, upstream of the solenoid, and before the RFQ entrance.

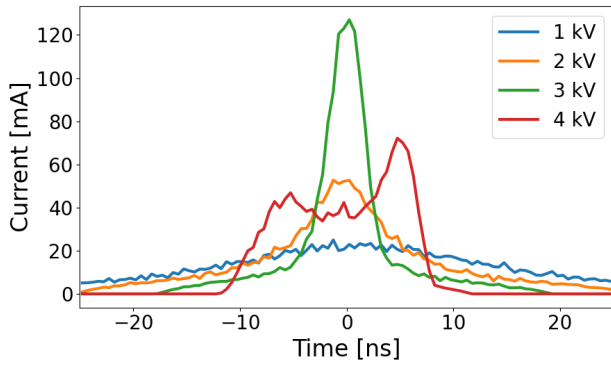


Figure 6: Beam current profiles upstream of the RFQ for varying LFB voltages with a 101.6 mm beam-pipe OD and 25.4 mm gap size.

velocity modulation compresses the beam longitudinally, increasing the peak current while reducing the bunch width. Before entering the RFQ, the bunch reaches a peak current of 129 mA with a FWHM bunch width of 4.01 ns, matching the 5 ns RFQ RF period. Low-current longitudinal tails are produced by particles at the edges of the initial 150 ns chopped beam pulse that do not experience the optimal RF phase for bunching.

Figure 6 shows the beam current profile immediately upstream of the RFQ for varying LFB voltages using a 101.6 mm OD beam pipe and 25.4 mm gap size. Increasing the bunching voltage from 1 kV to 3 kV compresses the beam and increases the peak current while reducing the bunch width. At 4 kV, the beam becomes over-bunched, producing a broader double-peaked distribution and reduced peak current.

RFQ PIC Studies

PIC simulations were performed for LFB voltages ranging from 1 kV to 4 kV and beam-pipe ODs of 50.8 mm, 76.2 mm and 101.6 mm. For each configuration, the fully bunched beam was simulated through the 201.25 MHz RFQ to evaluate beam capture and transmission.

Figure 7 shows that the bunching voltage strongly affects the amount of charge captured within a single RFQ RF bucket. The highest average bucket charge of approximately 43 pC was obtained for the 76.2 mm OD beam pipe operating at 3 kV. For this configuration, the peak bunch current reached 506 mA with 91.1 % bunch transmission through the RFQ. Lower bunching voltages produced insufficient bunch compression, while operation at 4 kV tended to over-bunch the beam, reducing RFQ transmission and lowering the average output charge.

CONCLUSION

A 10.0625 MHz low-frequency buncher (LFB) was designed and evaluated for the RFQ Test Stand (RFQTS) at LANSCE using electrostatic and particle-in-cell (PIC) simulations. Transit-time factor studies showed that gap size

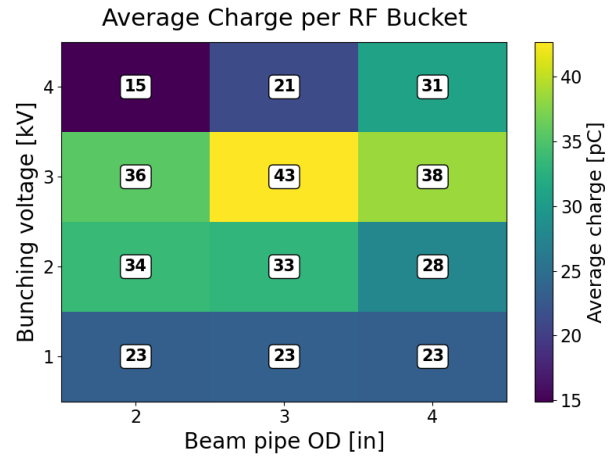


Figure 7: Average charge captured per RF bucket at the RFQ output for varying LFB bunching voltages and beam-pipe outer diameters.

had a relatively weak effect on the TTF, while the beam-pipe outer diameter (OD) had a stronger influence on bunching performance.

PIC simulations showed that the LFB successfully compresses a 35 keV, 15 mA proton beam into approximately 5 ns bunches suitable for injection into the 201.25 MHz RFQ. Simulations through the RFQ demonstrated that a beam-pipe OD of 76.2 mm with an LFB operating voltage near 3 kV provided the best bunching performance. The optimal configuration produced an average charge of approximately 43 pC per RF bucket, a peak bunch current of 506 mA, and 91.1 % bunch transmission through the RFQ. These results demonstrate that the proposed LFB design can reproduce the high peak-current beam conditions required for future RFQTS and LAMP operations.

ACKNOWLEDGMENTS

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