PROGRESS TOWARDS AN RFQ-BASED FRONT END FOR LANSCE*

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Abstract

The LANSCE linear accelerator at Los Alamos National Laboratory provides H^- and H^+ beams to several user facilities that support Isotope Production, NNSA Stockpile Stewardship, and Basic Energy Science programs. These beams are initially accelerated to 750 keV using Cockcroft-Walton (CW) based injectors that have been in operation for over 37 years. They have failure modes which can result in prolonged operational downtime due to the unavailability of replacement parts. To reduce long-term operational risks and to realize future beam performance goals in support of the Materials Test Station (MTS) and the Matter-Radiation Interactions in Extremes (MaRIE) Facility, plans are underway to develop a Radio-Frequency Quadrupole (RFQ) based front end as a modern injector replacement for the existing CW injectors. Our progress to date will be discussed.

INTRODUCTION

The Los Alamos Neutron Science Center (LANSCE) currently supports a broad user base including the neutron scattering community, isotope production, basic science, and national security programs by providing multiple beams to several diverse experimental areas. The LANSCE linac accelerates negative hydrogen ions (H^-) and protons (H^+) simultaneously. An 800-MeV H^- beam is delivered at 20 Hz to the proton storage ring/moderated neutron production target for a suite of neutron-scattering instruments (Lujan Center), at 40 Hz to an un-moderated spallation target for nuclear physics cross-section measurements and microchip irradiations for industry (WNR), and on-demand at ~1 Hz for proton radiography (pRad) and at 20 Hz for ultra-cold neutron production (UCN). Protons are used for isotope production (IPF) at 100 MeV. High-power operation (10% total RF duty factor; 100 Hz x 625 μs; 16.5-mA peak proton beam current) has provided 800-kW average beam power at 800-MeV but was halted in 1998 after shut-down of the nuclear physics mission that supported high-power beam operations. Upgrades currently underway will allow high-power operation in support of new missions such as the Materials Test Station [1] and the MaRIE Fission Fusion Materials Facility [2] that will both require average beam powers in excess of 1 MW.

Beams are delivered to the LANSCE experimental areas on a pulse-by-pulse basis, initially accelerated in two CW-based injectors, for H^+ and H^- beams, respectively. At present, LANSCE delivers up to three different H^- beams based on user requirements. The highest average-current H^- beam (100-125 μA) is first accumulated in the proton storage ring (PSR) and then extracted to the moderated neutron spallation target at the Lujan Center. This beam is chopped to provide an extraction gap in the PSR circulating bunch. By comparison, the WNR facility typically requires a single linac micropulse every few microseconds within the standard 625-μs macropulse. Producing the widely-spaced single micropulses requires the use of a chopper and low-frequency buncher in the H^- injector. These micropulses typically contain about 2.5 times more charge than the standard H^- linac microbunch. The other two H^- beam users, pRad and UCN, have beam requirements that require chopped and pre-bunched beams somewhat similar to the Lujan beam. The present dual-beam CW-based injector scheme for the LANSCE linac is shown in Fig. 1. The two beam species are merged into a common beam transport line and bunched before injection into the drift-tube linac (DTL) with a capture efficiency of approximately 80%.

Typical parameters for the 60-Hz (present maximum beam repetition rate) H^- beams are given in Table 1. Comparing chopping requirements against duty factor for these three beams, two categories emerge: low-duty factor beams with modest chopping requirements (Lujan, pRad) and a high-duty factor beam with demanding chopping requirements (WNR). H^+ beam parameters are also shown in Table 1. Future 120-Hz, H^+ beam requirements are shown in Table 2. An average H^+ beam power of 25 kW (250 μA) is required to be delivered to IPF. An average beam power of 1-2 MW is expected to be delivered to MTS/MaRIE initially in 2016. Details of future plans for high-power beam operations can be found in Ref. 3.

A recent assessment of our CW injectors revealed two potential failure modes that could result in significant disruption of the beam operations at LANSCE. The first of these is failure of the accelerating column and/or SF6 acrylic jacket. No spare currently exists. Procurement of such a spare is both costly and a long-lead-time item. Also based on previous experience, approximately 4 months is required to perform a complete column change out with a spare column in hand. The second potential high-impact failure is of one or more of the support legs in the CW. These are load bearing members and there is engineering concern about their working lifetime. An extended downtime of several months is estimated in order to dismantle and rebuild the CW with new support legs, if even available.

* Work supported by the United States Department of Energy, National Nuclear Security Agency, under contract DE-AC52-06NA25396
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Our strategy to reduce operational risks associated with the current CW-based injector systems involves replacement of these systems with modern radio-frequency quadrupole (RFQ) based injectors. This will improve reliability by reducing the overall complexity of the systems and by removing reliance on antiquated CW hardware for which spare components are not readily available. RFQ accelerators are employed worldwide and have demonstrated stable and reliable operation. An RFQ-based injector also allows use of a more compact beam transport which reduces the number of active components of the overall system.

Table 1: Typical 60-Hz LANSCE beam parameters.

Beam/Area	Duty Factor	Chopping Specs
Lujan, H^-	20 Hz x 625 μs = 1.25%	290 ns burst every 358 ns
WNR, H^-	40 Hz x 625 μs = 2.5%	Single micropulse every 1.8 μs
pRad, H^-	1 Hz x 300 μs = 0.03%	20-30, 60 ns beam bursts, variable spacing
UCN, H^-	20 Hz x 625 μs = 1.25%	Variable
IPF, H^+	40 Hz x 625 μs = 2.5%	None

Table 2: Future 120-Hz LANSCE H^+ beam parameters.

Beam/Area	Duty Factor	Ave. Current
IPF	20 Hz x 770 μs = 1.54%	250 μA
MTS/FFMF	100 Hz x 770 μs = 7.7%	1.25 mA

Implementation of RFQ-based injectors is also integral to meeting the high-power performance goals for MTS and MaRIE. The RFQ offers improved beam quality (smaller beam emittance) and a bunched beam better suited for injection into the next accelerator section (higher capture efficiency), the DTL. The improved beam emittance and higher capture efficiency are expected to reduce beam losses at higher beam energies which cause structure activation when operating at high-average beam power.

RFQ REQUIREMENTS

To meet the above requirements and to reproduce all existing beam delivery capabilities, including the high duty factor and demanding chopping requirements for the WNR beam, we are considering a 3-RFQ upgrade to the present injector system. Figure 2 shows the conceptual layout for this new 3-RFQ system. A single 201.25-MHz RFQ will provide bunched but un-chopped H^+ beam of up to 35 mA. A second 201.25-MHz RFQ will provide bunched and chopped H^- beam for Lujan, pRad and UCN. Finally, a third lower-frequency RFQ, at possibly 67 MHz, will produce the intense single H^- linac micropulses for WNR. This 3-RFQ scheme should allow the most flexibility while meeting all beam requirements. A single 201-MHz RFQ option was considered for all H^- beams but initial studies suggest that the WNR beam intensity and beam purity requirements cannot be met with this option. As is shown schematically in Fig. 2, beams from the two H^- RFQs would first merge into a single H^- beam transport line. The H^- beam would then be merged with beam from the H^+ RFQ. All beams would share a relatively short, common transport line just upstream of the DTL.

Implementation of the 3-RFQ scheme will be staged, with development of the H^+ RFQ having highest priority due to its impact on high-power performance goals. It is also the simplest system to implement first. Although the RFQ will first be operated and commissioned on a separate test stand, our goal is to develop an H^+ RFQ design and beam-transport layout compatible with the existing H^- CW injector by requiring no further changes beyond the merging dipole leading the common H^+/H^- beam transport section (See Fig.1). This will allow for early implementation of the new system. Figure 3 shows a schematic layout of the H^+ RFQ implemented with the existing H^- CW and associated transport line.

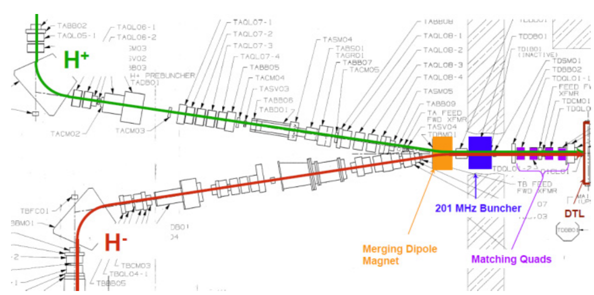

Figure 1: Present H^+/H^- CW injector layout.

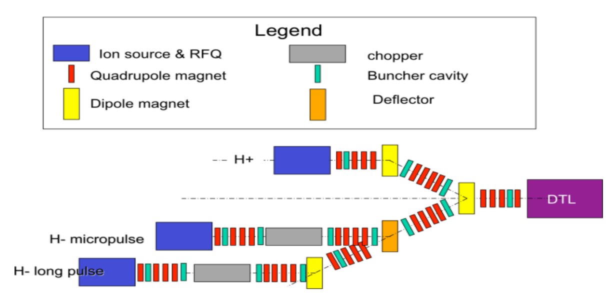

Figure 2: Conceptual layout of the 3-RFQ H^+/H^- injector system for LANSCE.

RFQ Injector Conceptual Design

Based on cost and recent successes such as the ISIS CW-to-RFQ replacement, we have selected a 4-rod type RFQ as the structure of choice for our injector upgrade. For the H^+ RFQ we expect to use our present H^+ duoplasmatron ion source coupled to a short electrostatic LEBT for simple and reliable operation at the required beam current and duty factor. Appropriate H^- ion sources will need to be evaluated, as will a range of RFQ injection energies that give the best beam dynamics performance.

The new low-energy beam-transport lines following each RFQ must be compact to preserve the low beam emittances. To achieve this goal, we have designed a compact 201.25-MHz, quarter-wave buncher cavity that is only 8 cm long [4, 5]. We also plan to take advantage of the compact SNS-style MEBT quadrupoles for transverse beam focusing. Both are also shown in Fig. 3. Detailed specifications for the RFQ are under development.

Technical Evaluations to Date

A very preliminary design of a 750-keV, 201.25-MHz RFQ (nominal 26-mA peak current H^+ beam) with an injection energy of 35 keV has been completed using the PARMTEQM code [6] and a layout of a beam transport section between the RFQ and the existing transport merging dipole has been completed using TRACE-3D [6], as shown in Fig. 4. DTL simulations using the PARMILA code [6] have validated the multi-particle beam dynamics and linac capture (estimated to be 91%).

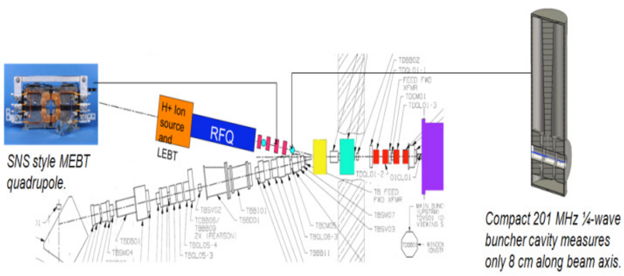

Figure 3: Shown is the conceptual design layout of the new H^+ RFQ-based injector (upper left) merging with the existing 750-keV H- beam transport line.

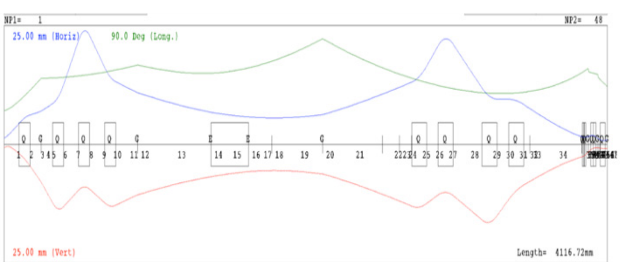

Figure 4: TRACE 3-D beam envelope model of the 750-keV bunched beam transported from the RFQ output to the 3rd cell of the DTL.

DESIGN AND ACQUISITION APPROACH

Our present plans to complete detailed physics and engineering designs, and fabrication of the RFQ will be in collaboration with the Institute of Applied Physics (IAP) – Goethe University, Frankfurt, Germany. The IAP will be responsible for fabrication of the RFQ and its delivery to Los Alamos.

The physics design will be done as an iterative process between Los Alamos and the IAP, with both institutions doing simulations with PARMTEQM. Los Alamos will further validate the design results using the Micro Wave Studio (MWS) suite of codes [7].

Primary mechanical design responsibility will belong to the IAP, however the design will be validated through thermal modelling at Los Alamos using the ANSYS [8] code and the design iterated if necessary to meet well-defined performance requirements.

The RFQ is required to operate at a high duty factor of up to 15%. We expect our design approach to eliminate any issues related to cooling the structure. We also plan on investigating and better understanding end-region field effects, and developing improvements to the mechanical structure design, cooling, and tuning.

After fabrication of the RFQ is complete, the alignment, tuning, and low-power testing will be done in Germany with Los Alamos participation. All necessary preparations for the test stand should be completed at Los Alamos by the RFQ delivery date so that high-power testing and commissioning with beam can be done. These preparations include building support structures and beam transport-line components; procuring magnets, RF systems, and vacuum systems; as well as developing the appropriate diagnostics and controls required.

We are currently in the process of building the needed detailed simulation models in PARMTEQM and MWS, beginning RFQ injection-energy trade-off studies, and working towards getting the R&D collaboration agreement in place between our two institutions. We expect delivery of the RFQ in the next 18-24 months.

This project is funded through internal laboratory funding in support of LANSCE Risk Mitigation [9] and is strongly endorsed by the MTS and MaRIE project management. If our approach is successful, we expect to likewise design and build the H^- RFQs needed to fully complete our injector system upgrade.

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