STATUS OF THE LANSCE FRONT END UPGRADE*

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Abstract

Initial acceleration of the beams in the LANSCE linear accelerator at Los Alamos National Laboratory is still presently accomplished through the use of two 750-keV Cockcroft-Walton (CW) based injectors. To reduce long-term operational risks and to realize future beam performance goals, plans are underway to replace the existing H^+ CW injector with a modern replacement, 4-rod Radio-Frequency Quadrupole (RFQ) based front end. Significant technical progress has been made since we last reported on this project. Status and progress of the design and fabrication of the RFQ, the RF system, beam transports, and integrated accelerator test stand 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 restore full 120-Hz operations and allow high-power operation in support of planned new missions [1] that will require MW-level average beam powers.

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 at 100 MeV. An additional average beam power of 0.75 MW at 800 MeV is expected to be available for other applications beginning in 2017. Several options for enhanced future high-power beam operations can be found in Ref. 2.

Assessment of failure modes of our CW injectors revealed the potential for significant disruption of the beam operations at LANSCE [3] either due to catastrophic failure of major components and/or unavailability of spare parts.

Our strategy to reduce operational risks associated with the current CW-based injector systems involves the eventual replacement of these systems with modern radio-frequency quadrupole (RFQ) based injectors. Reliability is expected to improve due to reduced overall complexity of the systems and by modernization. RFQ accelerators are employed worldwide and have demonstrated stable and reliable operation.

To meet the above requirements while maintaining 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 [3] to the present injector system that would be implemented in a staged approach with development of the H^+ RFQ having highest priority due to its impact on our near-term

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high-power performance goals. In this scheme (shown conceptually in Fig. 2), 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.

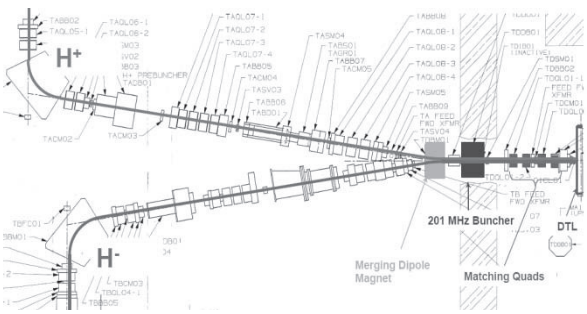

Figure 1: Present H^+/H^- CW injector layout.

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 (100 MeV)	20 Hz x 770 µs = 1.54%	250 µA
Area A (800 MeV)	100 Hz x 770 µs = 7.7%	0.75-1.25 mA

We have developed an H^+ RFQ design and beam-transport layout compatible with the existing H^- CW injector that require no changes beyond the merging dipole upstream of the common H^+/H^- beam transport section (See Fig.1). This will allow for early implementation of the new H^+ system, independent of the longer-term plans to implement multiple RFQ injectors. Following completion of the RFQ, the RFQ will first be operated and commissioned on a separate test stand prior to integration at the front end of the LANSCE linac.

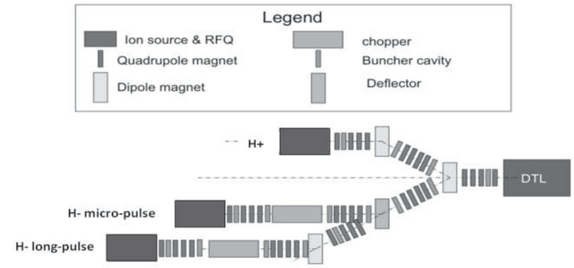

Figure 2: Conceptual layout of the 3-RFQ H^+/H^- injector system for LANSCE.

PROJECT STATUS

RFQ

The final physics design of the 4-rod RFQ has been completed and accepted. The physics design was completed and verified through a joint effort between the Institute of Applied Physics (IAP) at Goethe University, Frankfurt, Germany, and Los Alamos [4].

A final mechanical design review was held in April 2013. Fabrication of the RFQ is expected to take 9-12 months in Germany by our project partner Kress, GmbH, with delivery to Los Alamos before the end of 2014.

The RFQ is required to operate at a high duty factor of up to 15% and must meet strict beam performance requirements. Complementary simulations using the TRACE 2-D/3-D, PARMTEQM and PARMILA codes [5], Beampath [6], the CST Studio suite of codes [7] including Particle Studio, and the ANSYS [8] code were used to validate the design results.

To ensure mechanical and operational robustness of the RFQ, several technical evaluations were completed prior to acceptance of the design [9]. These included: addressing potential structure cooling issues, evaluation of tuning range, impact of stem spacing on frequency and field flatness, impact of vane cross-section and stem geometry on dipole fields, and investigation of end-region field effects on emittance growth and final output energy.

Ion Source and Low-Energy Beam Transport

The extraction geometry of our present H^+ duoplasmatron ion source, normally operated at a 35-kV extraction voltage, has been redesigned to produce a 35-mA beam with a transverse emittance of < 0.02 π-cm-mrad, normalized [10]. Modifications to an existing source and testing will be required to verify the new design.

Although previously a short electrostatic LEBT for beam matching from the ion source to the RFQ was considered, a new 2-solenoid magnetic LEBT has been designed and optimized to transport beams over a wide range of space-charge neutralization and transverse emittance, while allowing sufficient space for diagnostics and a beam deflector [10]. The design layout minimizes the beam size in the LEBT and potential emittance growth due to solenoid aberrations.

RF System

After fabrication of the RFQ is complete, the alignment, tuning, and low-power testing will be done in Germany with Los Alamos participation. High-power testing will be done at Los Alamos and is expected to use the High Power Test Facility at LANSCE [11]. The RFQ will be tested at full peak power and the full 15% duty factor (120 Hz, 1250 μs RF pulse length) using the 201.25-MHz Thales TH781 Intermediate Power Amplifier and associated low-level RF controls capability of the test facility. The estimated full peak power required for the test is 90-100 kW, assuming a realistic surface conductivity and a 15%-20% additional power margin. Design of the final RFQ RF system has not yet started.

Medium-Energy Beam Transport

A new Medium-Energy Transport (MEBT) line to match the RFQ output beam into the DTL has been designed to replace the existing H^+ beam transport line shown in Fig. 1 [12]. The MEBT must be as compact as possible to preserve the beam emittances. To do so, we plan to use multiple compact 201.25-MHz quarter-wave bunchers [13] to minimize the beam phase spread and compact SNS-style MEBT quadrupoles for transverse beam focusing (See Fig. 3). Simulation studies have been completed using the TRACE-3D [5] and PARMILA [5] codes to validate the multi-particle beam dynamics and linac capture (estimated to be 81%).

RFQ Test Stand

Our original plan was to have all necessary preparations for the test stand completed at Los Alamos by the RFQ delivery date so that high-power testing and commissioning with beam could be completed, followed by demonstration over the course of a year of stable operations prior to implementation on the LANSCE linac. However, recent schedule and budget changes require a more phased approach to testing and commissioning of the RFQ.

As mentioned above, preparations are already underway to perform high-power testing of the RFQ. In parallel to fabrication of the RFQ, an intermediate-stage 35-keV ion-source test stand will be assembled, including the LEBT and sufficient diagnostics to confirm performance and reliability of the source, and to match and characterize the beam into the RFQ. Ion-source and high-voltage components have already been procured, with assembly of the test stand to begin soon.

Ongoing efforts to layout the full RFQ Test Stand that will include the ion source, 35-keV high-voltage system, LEBT, RFQ, RF system, MEBT, diagnostics, and controls will continue. 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.

Particular emphases of the RFQ Test Stand will be long-term reliability and availability of the RFQ and associated systems, and the constraints imposed by dual-species operation of the LANSCE linac on the phase-space distributions of the beam from the RFQ injector. Good measurements of the beam properties, including matching to the DTL, are therefore required during the testing phase of the RFQ [14]. All components of the test stand are being designed to be compatible with implementation as a full replacement system on the LANSCE linac including support structures and all mechanical systems such as vacuum and cooling manifolds, etc.

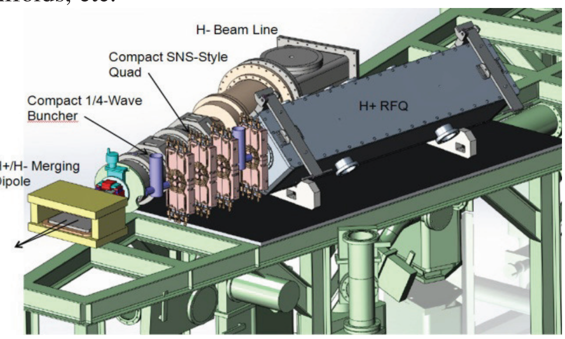

Figure 3: Shown is a preliminary engineering layout of the new H^+ RFQ injector, compact quads, and compact bunchers on the existing LANSCE beam transport line.

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