POSSIBLE UPGRADE PATHS FOR THE LANSCE H$^-$ INJECTOR*

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Abstract

The LANSCE linac presently provides both H$^-$ and H$^+$ beams to several user facilities. The H$^-$ injector uses a cesiated, multi-cusp field, surface converter source operating at duty factors between 10 and 12%, coupled to a Cockcroft-Walton (CW) accelerator to provide peak beam currents of ~13 mA for the LANSCE linac. In an effort to raise the peak beam current available to the majority of the H$^-$ users, we are pursuing two options. The first is composed of a low duty factor H$^-$ ion source and a 750 keV Radio Frequency Quadrupole (RFQ) that would provide higher peak currents for use by the Lujan and pRad programs. The second consists of a low frequency buncher for the existing 80 keV beam transport located inside the CW dome that would increase the peak beam current for the WNR program. This paper will present these two options.

INTRODUCTION

The LANSCE linac is comprised of a 100-MeV drift-tube linac (DTL) and an 800-MeV coupled-cavity linac. The DTL is fed by two Cockcroft-Walton based injectors that produce 750 keV H$^+$ and H$^-$ beams for the various user programs. The linac is a pulsed machine and operates at a typical pulse repetition rate of 120 Hz and a beam pulse length of 625 µs. However, recently the beam gate has been extended up to 775 µs to provide the users with additional beam on target. The present H$^-$ injector uses a cesiated, multi-cusp field, surface converter source operating at ~10-12% duty factor to supply peak beam currents of ~13 mA to the linac.

In general it is beneficial from the experimental program standpoint to maximize the average beam current on target. This can be done by raising the peak current or increasing the duty factor. The latter is often easier but more costly as it translates into higher operating costs. The former is usually more difficult but results in improved operational efficiencies. Efforts to increase the H$^-$ peak current provided by the injector have been underway for some time. Unfortunately, increasing the current while maintaining beam quality from this ion source operating under these conditions has been a difficult task and a solution has not yet been found. An alternative approach that we are pursuing is based upon the application of technology that targets the specific range of pulse pattern and duty factor requirements for the H$^-$ beams that LANSCE provides. These upgrade paths are described below.

PRESENT H$^-$ OPERATIONS

Beams are delivered to the LANSCE user facilities on a pulse-by-pulse basis. Typical parameters for the three main H$^-$ beams are given in Table 1. Comparing micro-pulse 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). This dichotomy in beam requirements suggests that different approaches to increasing the peak beam current might be more appropriate than a single one.

Table 1: Nominal H$^-$ Beam Parameters

Beam	Duty Factor	Chopping Specs
Lujan	20 Hz x 625 µs = 1.25%	290 ns burst every 358 ns
pRad	1 Hz x 300 µs = 0.03%	20-30, 60 ns beam bursts, variable spacing
WNR	100 Hz x 625 µs = 6.25%	Single micro-pulse every 1.8 µs

UPGRADE PATHS

Ultimately our goal would be to replace the CW-based injectors with RFQ technology. This would address maintenance, reliability and maintainability issues associated with the CW but would not result in any sizable increase in peak beam current with the existing H$^-$ ion source. Higher peak current H$^-$ ion sources exist but cannot meet our duty factor (10-12%) and lifetime requirements (28 days).

The alternative approach that we are pursuing is to address the two distinct beam requirements categories separately. A new RFQ and ion source combination would be developed to provide beam to the Lujan Center and pRad facilities. This system would only be required to operate at beam duty factors of ~1.3% or less. This relatively low duty factor opens up other options for ion source technology. The new RFQ injector would be installed in place of the old polarized H$^-$ injector beam transport. A new buncher system, to be located in the CW dome near the ion source, would be implemented for the WNR beam, which operates at the largest duty factor. The present injectors along with new hardware components are shown in Figure 1. This approach will allow us to raise the peak current for all three beams by a sizeable amount in the near term. In parallel, ion source development continues with the goal of producing a high peak, high duty factor H$^-$ ion source that would one day be used in conjunction with the RFQ to provide beam to all H$^-$ users.

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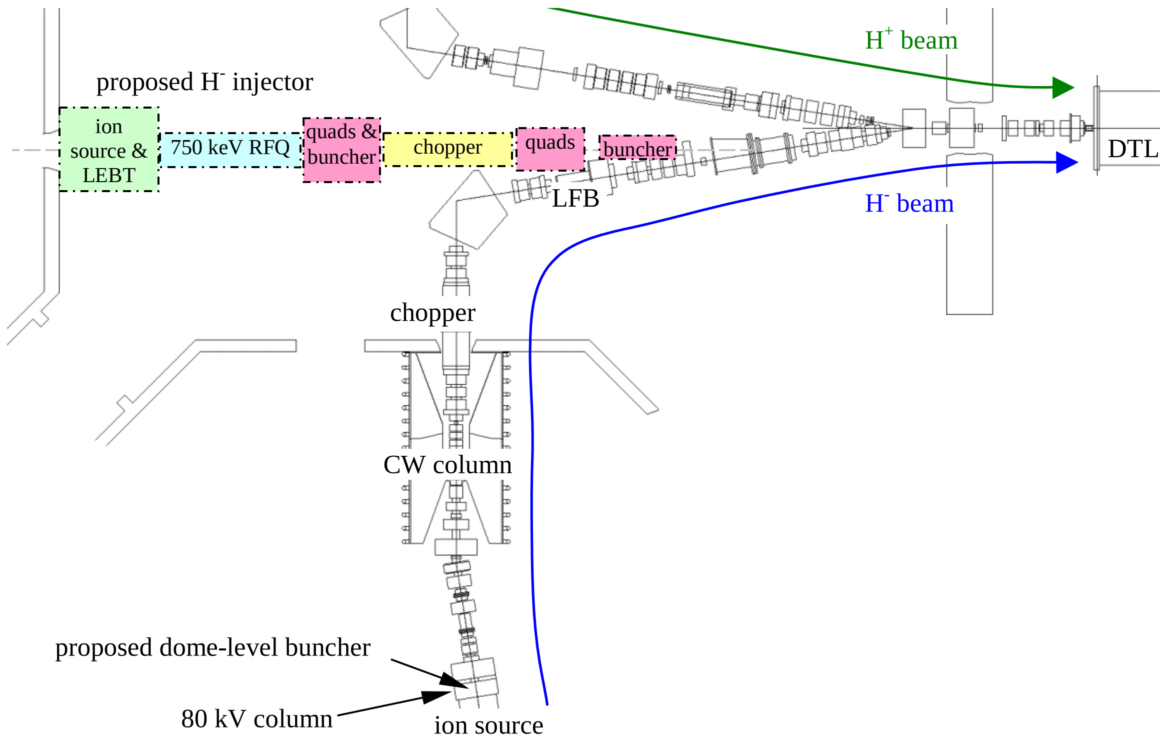

Figure 1: Partial top view of LANSCE injectors with proposed RFQ-based injector and dome level buncher shown schematically.

RFQ-BASED INJECTOR

The proposed upgrade to increase the peak current to the Lujan and pRad facilities is based upon the design of a new injector recently installed at the ISIS facility [1] and would consist of a Penning ion source and a 750 keV, 201.25 MHz RFQ. The ISIS ion source has demonstrated peak currents in excess of 35 mA at 1% duty factor and lifetimes of up to 40 days [2] and therefore could provide ample peak current and days of service for our application. Although the beam emittance is somewhat larger than from our present source, we are considering a reduction in slit aperture size that would reduce the emittance at the expense of current but still allow us to meet our goals [3]. Combining this source with an RFQ with high capture efficiency (>90%) we anticipate being able to deliver 135 μA of beam to the Lujan target with an overall beam duty factor below 1%. This will provide a sizable increase over present operations (80-120 μA average current) and additional capability for higher power operation in the future. Additional benefits from higher peak current operation to the Lujan target are lower operating costs through a reduction in beam pulse length and therefore RF duty factor, and lower integrated beam losses in the proton storage ring (PSR) through a reduction in accumulation time.

We are considering a four-rod RFQ design similar to the ISIS RFQ. This style has some advantages over the basic four-vane design, e.g. lower fabrication costs, less stringent mechanical tolerances and lack of dipole mode excitation [4][5]. However, because of the somewhat lengthy transport between the RFQ and DTL, particular attention will be paid to the energy spread of the output beam to help reduce the number of intermediate buncher cavities required. This RFQ would be designed to operate up to a maximum duty factor of ~12% in anticipation of future operation with a high duty factor, high-peak ion source.

Besides the ion source and RFQ, additional beamline hardware would be required to complete the injector. A low-energy beam transport (LEBT) is required for matching the ion source output beam to the RFQ acceptance. A slow-wave chopper would be installed downstream of the RFQ to intensity-modulate the beams for the Lujan and pRad programs. One or more 201.25 MHz buncher cavities will be required to preserve the longitudinal character of the beam on its way to the DTL. Groups of quadrupole magnets will be used to provide the transverse focusing following the RFQ. Finally, the output beam of this injector would be merged into the existing H^- transport by a 9 degree electrostatic deflector.

DOME-LEVEL BUNCHER

The dome-level buncher was conceived as a simple way to increase the peak current of the WNR beam since the high duty factor and stringent chopping requirements would not initially be met by the proposed RFQ injector. The H^- source, an 80 kV electrostatic column and ~3m long beam transport reside inside the CW dome. The CW is operated at 670 kV to accelerate the H^- beam up to 750 keV. Upon exiting the CW column the beam is focused and transported to a slow-wave chopper. For the nominal WNR operation, the chopper produces narrow, ~20-30 ns wide bursts of beam every 1.8 μs. These bursts are subsequently bunched by a 16.77 MHz cavity (low-frequency buncher or LFB) to increase the longitudinal capture by the DTL. This results in a single micro-pulse containing approximately 3 times the charge of a normal 201.25 MHz linac micro-pulse. Unfortunately, because of the large spacing between micro-pulses, most of the beam produced by the ion source is discarded. Employing a buncher in the dome is an effective way to better utilize the ion source output. Its effect is to raise the peak charge within the chopper window. Beam dynamics simulations were performed to evaluate the effectiveness of this technique in increasing the peak current for the WNR beam.

PARMILA [6] was used to perform simulations of the beam from the exit of the 80 kV column in the CW dome through the end of DTL tank 2. A cavity element was placed at the end of the column to simulate the effect of a new buncher device. Values for beam emittance and Courant-Snyder parameters were taken from slit-collector emittance measurements of the beam in the dome. Based upon measurements and comparison to beam envelope calculations, the space-charge neutralization is significant in the dome and in the transport up to the chopper, i.e. $I_{eff} \sim 1$mA. From the chopper through the end of tank 2 it was assumed to be zero. The chopper pulse width and LFB amplitude were adjusted to reproduce the observed capture/transmission of the present WNR beam. The simulation results indicate that a peak energy modulation of 1-1.5 keV introduced by the dome buncher will result in >30% increase in peak current at the end of DTL tank 2. Unfortunately, space is not available for a conventional cavity in the 80 keV transport.

The 1-1.5 keV energy modulation would be applied to the beam through application of RF to the second gap electrode of the 80 kV column (-30 kV wrt ground). A network is being developed that will incorporate a tuned circuit to reduce power consumption. Blocking capacitors will be used to preclude the high voltage DC from passing into the network. Chokes will be added to the existing DC supply leads connecting to the column electrodes to keep the RF currents out of those power supplies. A fiber optic system will be used to bring a synchronization signal into the dome to phase-lock the dome-level buncher with the chopper and LFB located in the 750 keV transport. A simple model of a single particle transiting the column was used to evaluate the effectiveness of modulating the beam energy through application of rf to the column electrode. The results of the simulations showed a peak rf voltage of 1.5-2 kV at 16.77 MHz rf would be required to produce the 1-1.5 keV of energy modulation on the beam. The system will operate in a pulsed mode at the WNR beam duty factor.

CONCLUSIONS AND OUTLOOK

The LANSCE H^- injector operates under demanding conditions. Upgrading this system to simultaneously provide more beam current to all H^- user programs remains a challenge. An alternative approach discussed in this paper applies technology matched to the individual beam requirements with an eye towards the future. A low-frequency buncher system would enable higher peak currents for the WNR beam, which operates at the highest duty factor and most demanding micro-pulse requirements. Work is currently underway to develop a prototype unit to demonstrate on the H^- ion source test stand by the end of 2006. A Penning ion source and 750 keV RFQ would provide a significant increase in peak current for the Lujan and pRad beams and provide a path forward for eventual replacement of the CW-based injectors. We are investigating funding options for this upgrade.

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