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H^+ AND H^- ION BEAM INJECTORS AT LANSCE: BEAM PRODUCTION STATUS AND PLANNED INJECTORS UPGRADES*

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Abstract

The Los Alamos Neutron Science Center operates with two 750 keV Cockcroft-Walton accelerators for simultaneous injection of H^+ and H^- ion beams into an 800 MeV linear accelerator. The proton ion beam is produced using a duoplasmatron source and the H^- ion beam is formed with a cesiated, multi-cusp-field, surface converter ion source. An overview of ion injector status, recent low energy beam transport (LEBT) line optimizations and ion source performance improvements will be presented.

To reduce long term operational risks and to improve existing LANSCE beam production for all facility users, new injector upgrades are underway: 1) replacing the H^+ CW injector with a Radio-Frequency Quadruple (RFQ) accelerator and 2) increasing H^- ion beam brightness and extending source lifetime using the novel SNS RF negative ion.

H^+ ION BEAM INJECTOR

The overall operation of the H+ injector continues to be relatively reliable and stable. It has been successfully operated for more than four decades at LANSCE. Our positive beam injector consists of a standard duoplasmatron ion source, 750 KV high voltage Cockcroft-Walton column and medium beam energy transport beam line connected to a merging beam dipole magnet in front of drift tube linear accelerator (DTL) [1]. The H^+ ion beam is accelerated to a final beam energy of 100 MeV. With an average beam current of 225 uA, the proton beam is currently used by the Isotope Production Facility to satisfy national needs for radio-pharmaceutical isotopes [2]. The duoplasmatorn proton source was developed by M. Ardenne in 1948 [3]. It has found implementation in many particle accelerators around the world (CERN, BNL, LANL GSI...). The source plasma is created with thermally emitted electrons from the hot electrode, compressed dually (geometrically and magnetically) and directed towards the anode. The arc discharge produces a very high degree of ionization and high ion density over 10^{14} cm^{-3} in front of the anode [4]. The anode has a small opening radius of 0.3 mm on the axis of the source as the plasma expands into the high voltage extraction system. Plasma expansion after the anode orifice reduces the ion beam density and makes it easier for beam formation and transport. The LANSCE ion source has a modified Pierce electrode with direct beam extraction [1]. The extracted proton beams are tuned with different extraction voltages in order to get a very low transverse emittance of 2 x 10^{-3} π cm mrad [5] for typical $H^+/H_2^+/H_3^+$ beam species ratios of 70/25/5 %. Table 1 presents typical working parameters of the ion source within the medium beam intensity range of 10-25 mA over a range of duty factor that varies up to 10 %. The duoplasmatron source uses a direct-current (DC) heated cathode made from a nickel mesh covered with complex cathode coating materials based on barium, strontium, calcium oxides and diethyl carbonate. The LANSCE duoplasmatron has a version of Hull dispenser cathode discovered in 1939 [6] and is well suited for ion sources, having a demonstrated lifetime of 3 x10^4 hours. The hot cathode has an operating temperature around 800 °C. This cathode can achieve very high integrated lifetime in proton beam production at particle accelerators. The duoplasmatron cathode at LANSCE was replaced in August 2016 after seven years in proton beam production achieving over 36,000 working hours (37.6 A hours) with a very high availability (~100 %). The barium eutectic is stable to air or vacuum storage. The cathode surface covered with BaO multi-layers can be vented to atmosphere, even after eight months of beam production, and then restarted without replacing the cathode or without long initial outgassing preparation. This is a significant operational advantage.

Table 1: Production Proton Source Parameters

Parameter	LANSCE	Units
Cathode heating	23.0	A
H2 gas flow	0.7	sccm
Discharge current	5.9	A
Discharge voltage	160	V
Magnetic field	100	mT
Extraction voltage	21-27	kV
Proton current	10-21	mA
Maximum pulse length	840	µs
Repetition rate	60/120	Hz
Duty factor	5-10	%

H^- ION BEAM INJECTOR

The LANSCE negative beam injector consists of a surface converter ion source, 80 kV extraction column followed with a 3m long two solenoid LEBT, 670 kV high voltage Cockcroft-Walton (CW) column and 750 keV medium beam energy transport beam line [1]. The LANL H^- surface converter ion source is described elsewhere [7-9]. The present H^- ion source uses radial beam extraction and is configured with two hot tungsten filaments and nominally scheduled to operate for a 4 week period with a duty factor of 10% [8]. During LANSCE beam production in

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2018/2019, the required negative ion beams were delivered with stable output current, above 18 mA, with measured transverse horizontal/vertical emittances of ε<0.2 π mm mrad. Typical EPICS-recorded data of the extracted H^- ion beams and an evolution of each filament's relative differential resistance during an entire run cycle are presented in Figure 1. The filament relative resistance of both filaments were 5 % at the end of the run cycle showing clearly that the source run can be prolonged to 6-8 weeks when both hot cathodes would achieve the critical value for wire relative resistance of 12% which indicates imminent cathode failure [9]. Typical plots of the negative ion current recorded at the CW H^- Dome and transport B during 24 hours are presented in Fig. 2. The data indicates a capability to produce H^- beam currents over 16 mA with very high beam stability and a low level of H^- noise. Achieved arc-down rates were also very low, at 3-4 discharges per day. Recorded beam currents at 80 kV in the low energy transport indicate a small electron current component of 2-3 mA and an e/H- ratio close to 1:3. A limitation of the H^- injector system during beam production is the 80 kV voltage drop (up to 2-3 kV) during beam pulse gates. Tests of a new high voltage (HV) system concept to overcome the drop are in progress.

Several newly established changes in ion source preparation and beam tuning have contributed to recent improved beam performance: a) careful assembling of refurbished ion sources, b) established criteria for vacuum leak rate below L<3 x10^{-9} atm cc/sec during source reassembling and in the HV column; c) implementing use of a new alignment tool for converter head positioning; d) modifying water loop cooling of the converter electrode to reduce its working temperature, e) conditioning new filaments with low content of water in residual gases during initial outgassing process (eliminates chemical sputtering in wire degradation), f) optimizing source processing time from days to several hours g) tuning the source with lower arc voltage (150V-160 V) to reduce plasma sputtering rate of heavy elements (Cs, W, O, N, C) to reduce wire mass erosion, h) running cesium oven temperature at 150 -155 C (30-40 C lower temperature) to reduce H^- ion beam stripping in the plasma between converter and repeller, i) precise calibration of input-output signals for filaments U/I setups, arc discharge U/I parameters, Cs oven temperature monitoring etc., and j) installing a new polished molybdenum (Mo) converter electrode during the ion source cleaning process. All changes and modified procedures are incorporated in new LANL operational manuals for future beam production cycles. We have also recently demonstrated that an H^- ion source can replaced, cesium transferred, and be ready for the beam production in 12 hours.

BEAM INJECTOR UPGRADE PROJECTS

The upgrade project to replace the existing old 750 keV Cockcroft-Walton injector with a new H+ injector based on a 201.5 MHz 4-vane RFQ accelerator is in progress [10]. The goals are a) lower long term operational risk and b) improved capabilities in radioactive isotope production.

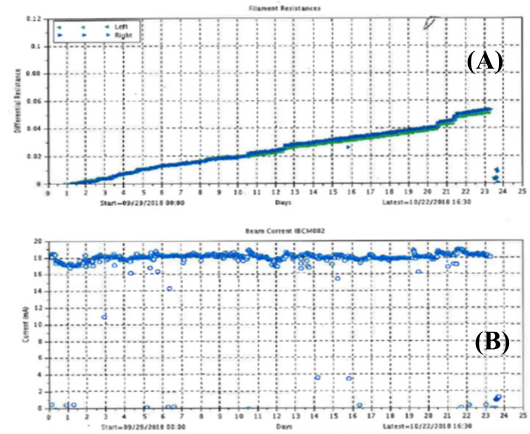

Figure 1: (A) Relative differential resistance, used as an efficient filament lifetime monitoring tool. (B) H^- beam current during the October beam production cycle.

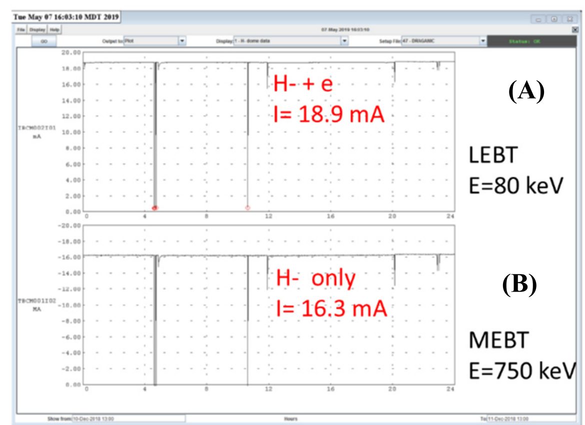

Figure 2: 24 hours charts of stable beam currents recorded at H^- beam injector: LEBT (A) and MEBT (B).

The selected H^+ ion source for the new injector is the duoplasmatron due to its high source performance, stability of production beam in the range of 20 to 30 mA, ion source reliability, simplicity in the design, LANSCE familiarity with existing cathode technology, operational ion source knowledge and many years of technical support, experience and expertise. The new design of the LEBT with two solenoids and new 35 keV extraction columns is shown in Fig 3 [11, 12]. The existing LANSCE duoplasmatron completely satisfies the new upgrade-project requirements. This proton source will be simple for turning on, high beam brightness tuning and regular maintenance. The new design of an H^+ RFQ test stand for comprehensive positive injector studies is shown in Fig. 3.

A second important ion source upgrade project at LANSCE started in 2018. For over three decades, the modest performance of our current H^- ion source is one of the major technical limitations to higher experimental throughput and new innovative uses of LANSCE.The main development goal is to install a new negative ion source at the LANL linear accelerator. The new radio frequency-driven plasma ion source at the ORNL-SNS facility has recently demonstrated high currents of H^- ion beams up to 60 mA

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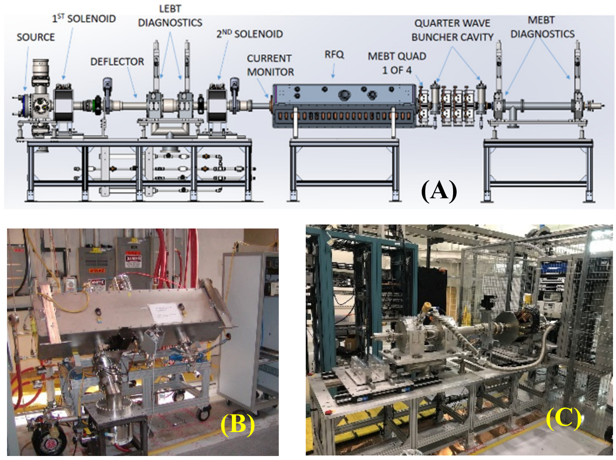

Figure 3: (A) Side view of new RFQ test stand model is shown. (B) new RFQ in preparation for high power test and commissioning and (C) recently assembled LEBT with the 35 kV high voltage platform.

with a duty factor of 6%, and fourteen weeks of source lifetime [13]. We plan to develop a similar ion source however, with a goal of achieving an H^- beam current of 30 mA with duty factor of 10 % and lifetime of 3 months using a version of the ORNL RF SPIS source with internal antenna (or external later). At the beginning of 2018, a collaboration between LANL and ORNL was initiated that included testing on the SNS test stand to realize the negative ion source upgrade project in a period of three years. In the summer of 2018 a first milestone was accomplished: the SNS RF ion source with internal antenna produced 25 mA H^- beam with a 10% duty factor in 28 days tests with one short plasma outage [14]. Ion beam extraction modeling with a single high-field-gradient electrode system and beam transport simulations using the new LEBT design are underway. The new design of a modified 80 kV high voltage column and RF ion source with internal antenna, to be demonstrated at LANSCE ion source test stand, is shown in Fig 4.

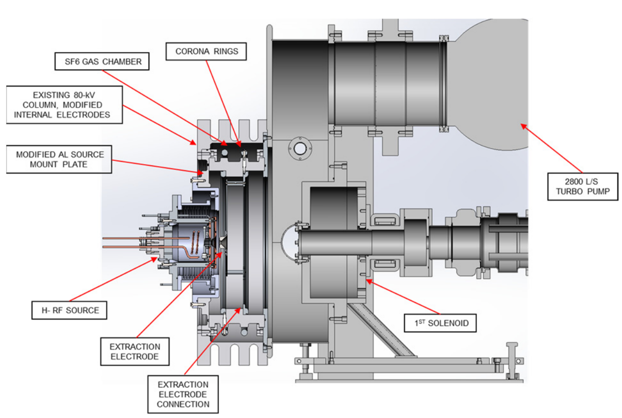

Figure 4: Cross section of SNS RF ion source with 80 kV extraction electrostatic column and two solenoid LEBT is shown.

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