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HIGH-BRIGHTNESS RFQ INJECTOR FOR LANSCE MULTI-BEAM OPERATION*

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Abstract

The LANSCE accelerator facility has been in operation for 50 years performing important scientific support for national security. The unique feature of the LANSCE accelerator facility is multi-beam operation, delivering beams to five experimental areas. The LANSCE front end is equipped with two independent injectors for H^+ and H^- beams, merging at the entrance of a Drift Tube Linac (DTL). The existing Cockcroft-Walton (CW) – based injector provides high beam brightness before injection into DTL. To reduce long-term operational risks and support beam delivery with high reliability, we designed an RFQ-based front end as a modern injector replacement for the CW injectors. Proposed injector includes two independent low-energy transports merging beams at the entrance of a single RFQ, which accelerates simultaneously both protons and H^- ions with multiple flavors of the beams. The paper discusses details of beam physics design and presents injector parameters.

INTRODUCTION

LANSCE linear accelerator consists of 201.25 MHz Drift Tube Linac accelerating particles from 0.75 MeV to 100 MeV and 805 MHz Coupled-Coupled Linac (CCL), accelerating particles from 100 MeV to 800 MeV. Accelerator facility simultaneously delivers various beams to multiple targets. Proton 100-MeV beam is delivered to Isotope Production Facility (IPF), while 800-MeV H^- beams are distributed to four experimental areas: the Lujan Neutron Scattering Center, the Weapons Neutron Research facility (WNR), the Proton Radiography facility (pRad), and the Ultra-Cold Neutron facility (UCN). The existing front end of accelerator is based on 50-years old Cockcroft-Walton (CW) accelerating columns and Drift Tube Linac. Analysis of beam availability within the last decades shows that a significant fraction of beam downtime (around 30%) is due to failures of the existing injector and Drift Tube Linac. Continuation of operation of that obsolete equipment leads to the risk of complete failure of facility operation.

To reduce long-term operational risks and to realize future beam performance goals in support of the laboratory missions, we develop a novel Front End including a high-brightness Radio-Frequency Quadrupole (RFQ) based injector [1]. The layout of the proposed injector is illustrated in Fig. 1 and the parameters are presented in Table 1. The new Front-End must provide the existing capabilities with a possible upgrade in beam intensity.

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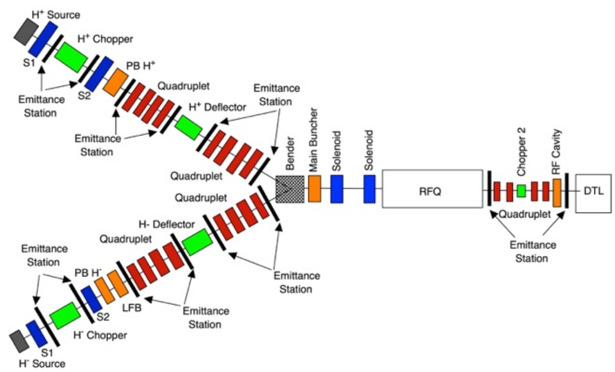

Figure 1: Layout of proposed RFQ-based 3-MeV injector.

Table 1: Parameters of the Proposed LANSCE Injector

Ions	H^+/H^-
Ion sources extraction voltage	100 keV
RF Frequency	201.25 MHz
RFQ energy	3 MeV
Repetition rate	120 Hz
Max beam peak current	32 mA
Average current	1.25 mA
Beam pulse	625-1000 µs
Number of RFQ cells	187
RFQ Length	4.2 m

DESIGN ISSUES FOR THE PROPOSED INJECTOR

The optimal operation of the accelerator facility critically depends on the emittance and brightness of the beam extracted from the ion sources and beam formation in the low-energy beam end. Normalized beam brightness is determined as

$$B = \frac{I}{8\pi^2 \varepsilon_{x\_rms} \varepsilon_{y\_rms}}$$

where I is the beam current, and ε_{x_rms}, ε_{y_rms} are normalized beam emittances in x- and y- directions. The H^+ beam injector operates with a duoplasmatron proton source which delivers a high-brightness beam with a current I = 10 - 30 mA, normalized rms emittance in the range ε_{rms} = 0.003 – 0.004 π cm mrad, and beam brightness B = 20 A/(π cm mrad)^2 [2]. The H^- beam injector is based on a cesiated, multicusp- field surface-production ion

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source with beam current I = 14-16 mA, normalized emittance ε_{rms} =0.018 π cm mrad and beam brightness B = 0.6 A/(π cm mrad)^2 [3]. The time structure of LANSCE beams was presented in Ref. [1]. While the accelerator facility delivers beams to 5 targets, there are 3 types of beams with different emittances and different charges per bunch (see Table 2). The typical time pattern of the accelerator includes 100 Hz of simultaneous acceleration of WNR/IPF beams and 20 Hz of acceleration of the Lujan beam. Beam delivered to pRad or UCN facilities, "steals" the cycles from WNR beam. During acceleration, the beams experience significant emittance growth.

The challenge of the present project is associated with the necessity to provide better than existing beam parameters while beam intensity is supposed to be increased and injection energy is reduced from 750 keV to 100 keV. In the proposed injector, beam space charge effects are stronger than in the existing one due to lower beam energy. Another aspect of the design of the injector is related to multi-component beam formation and acceleration in a single RFQ. Proposed RFQ must provide simultaneous acceleration of various intense beams with a high level of beam transmission and small emittance growth.

Table 2: Normalized Transverse RMS Beam Emittance (π cm mrad) and Charge Per Bunch (pC) in Existing LANSCE Accelerator

Beam (Facility)	Ion Source	750 keV	100 MeV	800 MeV	Charge /bunch
H^-(Lujan/pRad/UCN)	0.018	0.022	0.045	0.07	50
H^- (WNR)	0.018	0.024	0.058	0.124	125
H^+ (IPF), DTL only	0.003	0.005	0.026		20

LOW-ENERGY BEAM TRANSPORT

Preliminary design and study of the new injector were performed to evaluate the performance of the critical components of low-energy beam transport and the new RFQ. The injector consists of 2 independent, nearly identical beamlines for H^+ and H^- beams, merged into a common beamline in front of the RFQ. Each beamline contains a deflector, chopper, pre-buncher, Low-Frequency Buncher (in the H^- only), solenoids, and quadrupoles accompanied by emittance measurement stations to match the beam to key beamline points.

Besides the basic focusing elements, there are additional proposed beamline elements (see Fig. 2). There are 4 steering magnets, 5 beam current monitors, 2 beam stops, and 2 vacuum valves in each leg. The steering magnets are used to make fine adjustments to the beam direction. The current monitors are used to measure beam current along the beamline and in the Hardware Transmission Monitor (HWTM) system to control beam losses. The beam stops are used to terminate beam propagation during beam tuning. The vacuum isolation valves allow work on individual sections of the beamline without disturbing the vacuum in the other sections and close the beamline in case of pressure excursion. Beam collimators are placed in front of RF cavities and RFQ to remove outlying transverse particles, or beam halo. Additionally, a four-part collimator (jaw) is placed before bender magnet to remove part of the unchopped beam and for tuning purposes. The common beamline contains a bending magnet, the Main Buncher, and pair of solenoids to match beams to the RFQ, one steering magnet, a beam stop, and a vacuum valve. A number of ion pumps are placed along the beamline to provide distributed pumping. The typical vacuum required is 10^{-6} Torr to avoid H^- beam stripping and provide a necessary level of space charge neutralization on residual gas.

Particle trajectories in the beamline, calculated by the macroparticle code BEAMPATH [4], are presented in Figure 3. The first solenoid provides beam matching from the ion source to the chopper. The beam has a waist in the middle of the chopper. The second solenoid is used to create the beam waist in the Low-Frequency Buncher (H^- only) and Pre-Buncher. The subsequent combination of four quadrupoles (quadruplet) matches the beam to the deflector, creating a beam waist in the center of the deflector. The second quadruplet matches the beam to the Main Buncher, creating a beam waist in the Main Buncher. The last pair of solenoids matches the beam to the RFQ providing the required Twiss parameters at the entrance to RFQ.

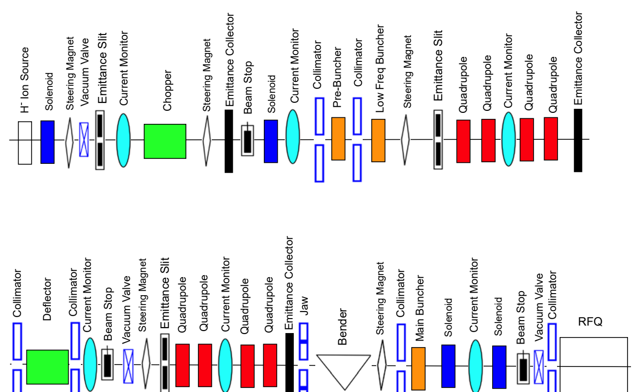

Figure 2: Layout of H^- leg of injector part with additional beamline elements.

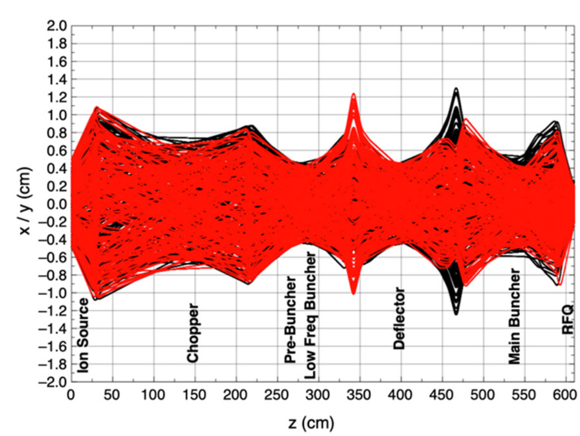

Figure 3: Particle trajectories in the injector beamline: (red) horizontal, (black) vertical.

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MULTI-BEAM RFQ

The primary challenge of the proposed project is the design of the multi-beam RFQ, since there is no such existing device in service for simultaneous acceleration of different intensity, charge, and time structure beam species of H^- and protons. The adopted approach of using pre-bunched beams has to date been demonstrated only in the case of single heavy ion beam acceleration with low current [5].

The RFQ is designed to accept three various types of beams described above. H^- (WNR) beam exists only as a sequence of single bunches separated by a long time interval of 1.8 μs, equivalent to 360 RF periods. The level of bunching of other beams is determined by the requirement to combine high beam capture and low emittance growth in RFQ. The RF frequency of RFQ f = 201.25 MHz is selected to be the same as that in the existing LANSCE accelerator. It is dictated by the necessity to provide the highest possible charge per single WNR bunch. It is supported also by the availability of the recently developed and installed high-power 201.25 MHz RF system for the LANSCE accelerator [6].

Table 3 illustrates the results of BEAMPATH simulation of beam dynamics in the designed RFQ. Simulations were performed separately for each individual beam injected in RFQ. The accelerator provides a high value of beam capture of 0.96 for preliminary bunched beam and lower capture of 0.84 for initially unbunched beam. However, beam emittance growth of unbunched H^+ (IPF) beam is noticeably smaller than that of the same bunched beam. Emittance growth of H^- (Lujan/pRad/UCN) beam is roughly the same for bunched and unbunched beam with significantly larger capture of the bunched beam.

Figures 4 and 5 illustrate the formation of two-component H^+ and H^- beam in RFQ from the simultaneous injection of initially unbunched beams with rms emittance ε_{rms} = 0.02 π cm mrad and charge per bunch 50 pC. For simplicity, both beams were supposed to be identical at the time of injection. It is seen, that after 55 RF periods beams become well bunched and spatially separated. Emittance growth and capture of both beams in case of simultaneous injection is roughly the same as that for separate injection of both beams. Further optimization of the proposed scheme will be required to improve multi-beam performance in the proposed injector.

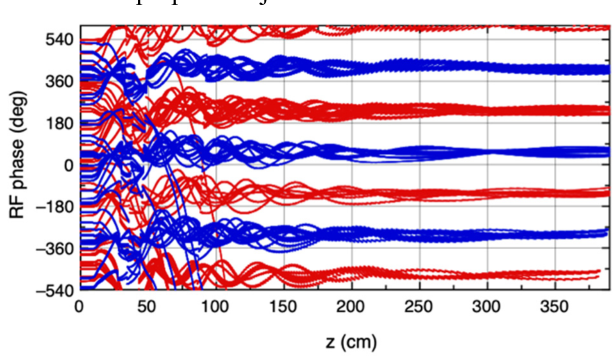

Figure 4: Phase trajectories in two-component beam in RFQ: (red) H^+ beam, (blue) H^- beam.

Table 3: Normalized Transverse RMS Beam Emittance (π cm mrad), Beam Capture in RFQ (in Parenthesis), and Charge Per Bunch (pC) in RFQ Injector

Beam (Facility)	Ion Source	100 keV	3 MeV	Charge /bunch
H^- (Lujan/pRad/UCN) unbunched	0.02	0.021	0.022 (0.84)	50
H^- (Lujan/pRad/UCN) bunched	0.02	0.021	0.022 (0.96)	50
H^- (WNR) bunched	0.02	0.024	0.028 (0.96)	240
H^+ (IPF) unbunched	0.003	0.004	0.006 (0.84)	50
H^+ (IPF) bunched	0.003	0.004	0.008 (0.96)	50

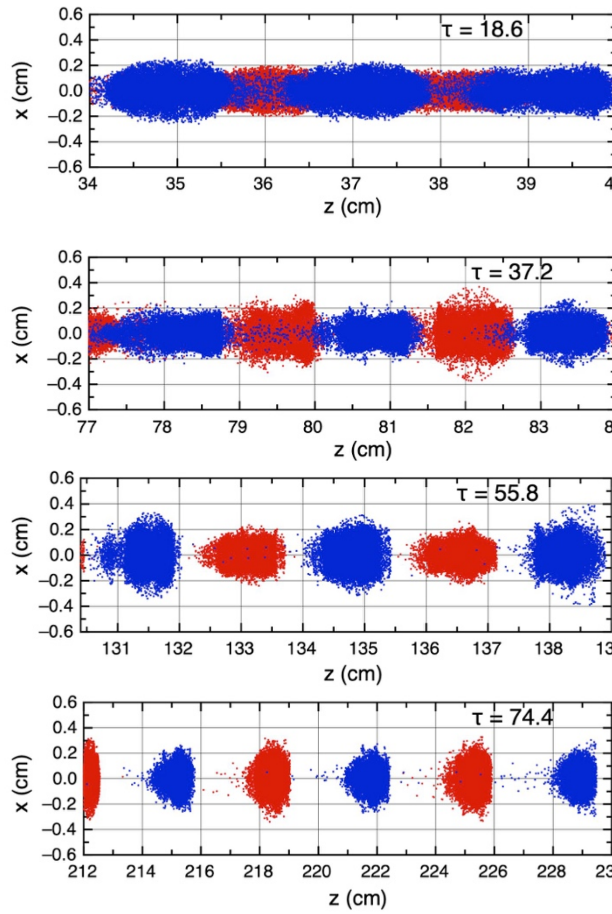

Figure 5: Formation of the two-component beam in RFQ: (red) H^+ beam, (blue) H^- beam; numbers indicate RF periods $\tau = tf$.

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