A 25-KeV, 30-MILLIAMP HYDROGEN-ION INJECTOR FOR A 200-MHz, 750-KeV RADIOFREQUENCY QUADRUPOLE

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Abstract

An injector development program is being pursued at Linac Systems for satisfying linear accelerator input beam requirements. Proton beams with 25-keV beam energy and 30-mA current with variable duty factors are presently being produced. The two main injector ingredients are a microwave plasma source and a single-einzel lens for matching the proton beam into the Radio Frequency Quadrupole (RFQ) accelerator. By realistic design simulation, the 25-keV rms normalized emittance is predicted to be 0.07 (πmm-mrad) after extraction from the plasma. The proton beam rms normalized emittance is predicted to grow to 0.24 (πmm-mrad) at the RFQ match point for 26 mA proton current. Insertion of a LEBT beam scraper reduces the predicted proton beam current to 15 mA with 0.085 (πmm-mrad) rms normalized emittance. A proton beam with these characteristics is predicted to have good transmission through the 4-bar, 200-MHz RFQ. Recent injector-RFQ measurements are confirming these design predictions, with 18-mA RFQ output current recently measured.

INTRODUCTION

Injectors based on microwave proton sources have been successfully used for four-vane RFQ applications [1,2,3]. Typically, these earlier works have used a solenoid magnetic lens system in the low-energy beam transport system (LEBT) to match the injector beam into the RFQ. Linac Systems has chosen an electrostatic (einzel lens) system for the RFQ beam matching. This LEBT choice gives a simple, low cost approach to the RFQ matching problem. The increase in the injector rms emittance is compensated by the larger phase-space acceptance of the radial strut 4-bar RFQ design [4].

This paper contains a description of the ion source and LEBT. Details on the mechanical components are contained in the following section. The subsequent section contains some of the prototype injector design considerations. This injector was used in the latest beam measurements on the 750-keV 4-bar RFQ where 18-mA RFQ output current was measured.

MECHANICAL DESIGN

A line drawing for the prototype Linac Systems proton injector is shown in Fig. 1. The 25-kV microwave ion source potential is electrically isolated from solenoid magnet power supplies, 2.45-GHz magnetron power supply, and the gas flow control. This eliminates the need for an expensive and complex isolated power system.

Components in Fig. 1 are (1) the electromagnetic solenoids which establish the 875 G on-axis field which forms the electron-cyclotron resonant (ECR) condition with the 2.45-GHz microwave power. The insulators (2) electrically isolate the solenoids and the LEBT vacuum box from the 25-kV extraction potential and the approximate 24-kV einzel lens voltage. The plasma chamber (3) is biased at +25 kV. The boron nitride (BN)

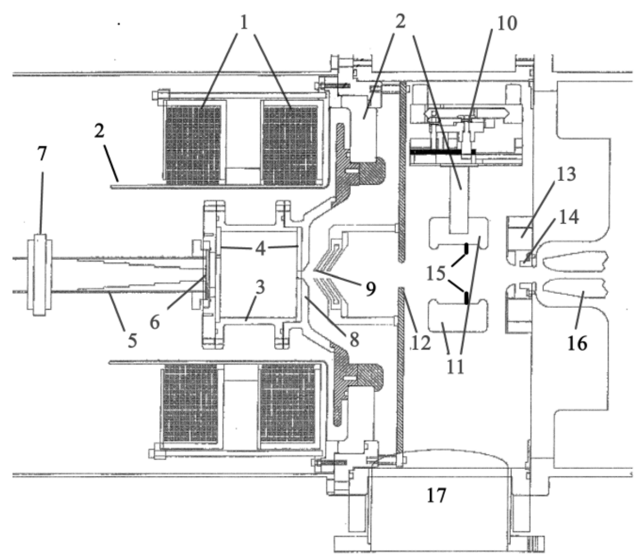

Figure 1. Line drawing of the Linac Systems prototype microwave proton source. Please see the accompanying text for the component description.

insulators (4) within the plasma chamber are an important contributor to the high-proton fraction nature of the microwave source [1,5]. Item (5) is a stepped-ridge microwave wave guide. The aluminum nitride vacuum window (6) is located between the waveguide and plasma chamber. The high voltage (HV) waveguide break (7) electrically isolates the magnetron power system from the plasma chamber. Item (8) is the plasma electrode at 25-kV potential which contains a 7-mm diameter hole from which particles diffuse from the plasma. The charged particles are then accelerated by the strong electric field formed between the puller electrode (9) and the plasma electrode. Contained within the puller electrode structure is another isolated electrode, the electron trap, which

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operates at -1 to -2 kV relative to ground, whose function is to prevent electrons from back streaming to the ion source. Further description of the ion extraction system is given below in the injector design section.

Several components are integral parts of the LEBT. The einzel lens is mounted on a xyz translation stage (10) (cf. Fig. 1). The einzel lens (11) is 6.30 cm long, with 5.4 cm aperture. The LEBT entrance aperture (12) has an inside diameter of 2.10 cm, and serves to electrically decouple the ion source and LEBT sections. It also scrapes some ion source halo beam. While the ion source operates at +25 kV, the einzel lens typically operates near +24 kV to give the best RFQ transmission. The injector beam current transformer (13) is used for measuring the RFQ input current, and is crucial for determining the RFQ transmission. The RFQ collar bias (14) traps electrons in the RFQ injection region; (16) shows the location of the RFQ vanes. The metal inserts (15) scrape beam at large radii inside the einzel lens where the beam power is low. Also, effects from secondary electron production are minimized by beam scraping within the einzel lens. The injector is pumped by a 400 l/s Alcatel turbo molecular vacuum pump backed with a Varian scroll pump (17). The overall injector length from the exit aperture of the ion source plasma electrode (8) to the RFQ matchpoint is 24.8 cm.

Figure 2 shows a photograph of the injector assembled with the 200-MHz RFQ. A Faraday cup is installed on the RFQ exit flange. With the injector beam current transformer (12), this Faraday cup current is used to measure the RFQ beam current transmission.

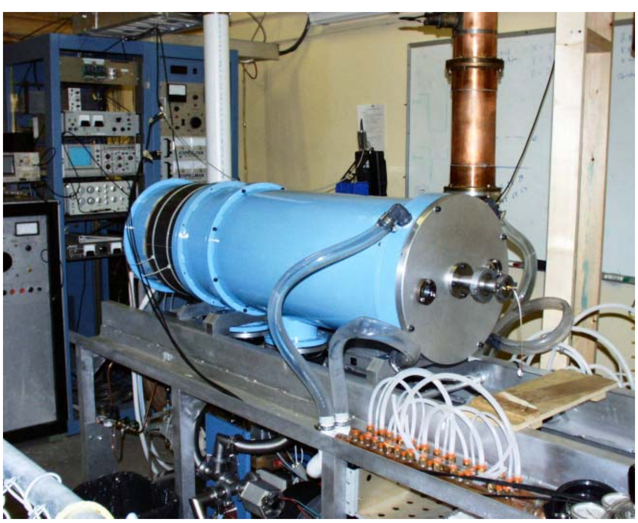

Figure 2. Photo of the injector in operating position with the 200-MHz, 750-keV RFQ.

INJECTOR DESIGN

Three finite element codes have been used in the injector design. The original design employed the AXCEL [6] and Vector Fields™ SCALA [7] code. At a later time, these results were checked with the 2-D PBGUNS™ code [8]. All codes take into account the beam space charge in the LEBT transport, while AXCEL and PBGUNS contain algorithms for self-consistent solution of the plasma sheath location. A comprehensive PBGUNS design exercise was carried out [8], and no significant improvements on the original AXCEL and SCALA designs were found.

Figure 3 shows a PBGUNS trajectory and equipotential simulation result for the Linac Systems prototype proton injector shown in Fig. 1. The radial coordinate R is plotted vertically while the Z coordinate (beam direction) is plotted horizontally. The cylindrical option is chosen

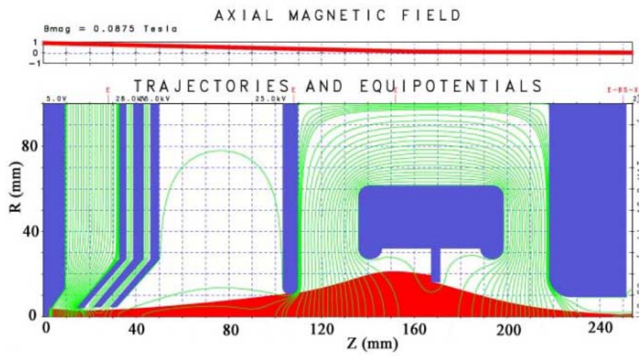

Figure 3. PBGUNS trajectory and equipotential plot for the 25 keV Linac Systems proton injector. For this simulation the einzel lens voltage is taken to be +24 kV.

for this simulation, as the system is generally rotationally symmetric about the R = 0 axis. The einzel lens support violates rotational symmetry. The plasma electrode is on the left with the modelled plasma region being located near Z = 2 mm and extending to R = 4 mm. The plasma density, beam extraction geometry, and 25 kV potential gives 18 mA total beam current at the RFQ match point (Z = 248 mm). The einzel lens beam scraper simulations predict a 12 mA current decrease as compared to the no scraper case. An 85% proton fraction is typical [5] for a well-conditioned microwave proton source, thus the simulation predicts 15 mA proton current at the RFQ location. Nomenclature for the four ion source electrodes (from the left) are (1.) plasma electrode, (2.) puller electrode, (3.) trap electrode, and (4.) ground electrode. Table 1 summarizes ion source physical dimensions in mm. When the proton plasma ion temperature kT_i = 1.0 eV is used in the simulation, the proton rms normalized

Table 1. Physical dimensions (mm) used in PBGUNS simulations for the ion source model shown in Fig. 3.

R_{pl}	G_{pul}	R_{pul}	G_{trap}	R_{trap}	G_{grnd}	R_{grnd}
3.5	11.3	4.0	4.2	4.48	3.8	4.48

where

R_{pl} = plasma electrode hole radius
G_{pul} = plasma-puller electrode gap
R_{pul} = puller electrode hole radius
G_{trap} = puller – trap electrode gap
R_{trap} = trap electrode hole radius
G_{grnd} = trap – first ground electrode gap
R_{grnd} = first ground electrode hole radius

emittance ($\varepsilon_{rms,n}$) is predicted to be 0.070 (πmm-mrad). This emittance is consistent with results from earlier experimental work [1,2].

Following downstream from the ion source, LEBT electrodes are the second ground electrode (entrance to the einzel lens region), the einzel lens, and finally the entrance aperture to the RFQ. Table 2 gives the physical LEBT dimensions in mm. Taking the kT_i = 1.0 eV case and V_{ein} = 24 kV, one finds that $\varepsilon_{rms,n}$ = 0.085 (πmm-mrad) at the RFQ match point (cf. Fig. 3). RFQ beam transmission simulations (without scraper ring) [10] show that beams with larger emittance are predicted to have order 90% transmission through the 4-bar RFQ.

Table 2. Physical units in mm for Linac Systems LEBT model shown in Fig. 3.

G_{grnd2}	R_{grnd2}	G_{1ein}	W_{ein}	R_{ein}	G_{2ein}
71.6	10.5	26.2	62.4	27.0	19.8

where

G_{grnd2} = ground 1 electrode to ground 2 electrode gap
R_{grnd2} = ground 2 electrode radius
G_{1ein} = ground 2 electrode to einzel lens gap
W_{ein} = einzel lens width;
R_{ein} = inner radius of einzel lens
G_{2ein} = einzel lens to RFQ entrance wall gap

LATEST INJECTOR-RFQ BEAM MEASUREMENTS

The oscillogram in Figure 4 shows results from the 25-keV proton injector operating with the 200-MHz RFQ.

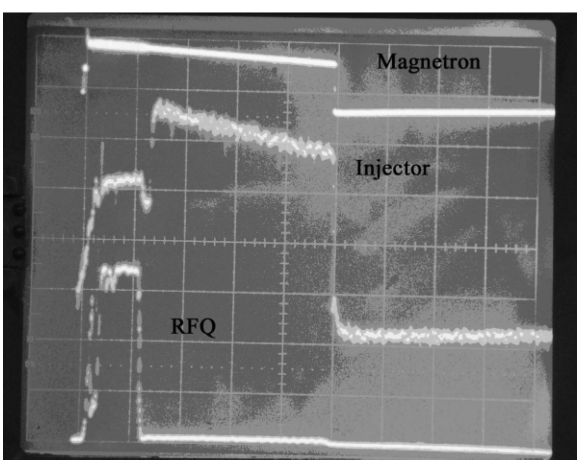

Figure 4. The top trace is the magnetron pulsed current (500mA/div), middle trace the injector beam current toroid (10mA/div), and (bottom) the RFQ output current measured in a Faraday cup (5mA/div). The time scale is 100 microseconds/div.

The time scale is 100 μs/div, thus the injector beam pulse lengths are 500 μs (top two traces.) The bottom trace is the Faraday cup signal, which was mounted on the RFQ exit flange (cf. Fig. 2). The RFQ output beam width was limited by the 200 MHz rf drive system to 100 μs pulse in order to limit the beam power to the uncooled Faraday cup. Up to 18 mA current was recorded in the Faraday cup located on the RFQ exit, before the Faraday cup failed from over heating. The injector beam current toroid signal is complex – cf. middle trace in Fig. 4. The collar bias ring insulator at the RFQ entrance failed in this measurement. Subsequent measurements have shown the enhanced current in the last 350 μs are secondary electrons that were not suppressed with the RFQ rf power off. Further measurements with higher power capability Faraday cup and the RFQ collar bias are planned.

The beam performance shown in Fig. 4 is the result of several recent upgrades made to the Linac Systems proton injector. These are:

1. A new longer duty factor magnetron pulser has been put into service.
2. A systematic EMI (electromagnetic interference) reduction program has been instituted on the injector.
3. A ring with a 32 mm diameter aperture has been installed near the midplane of the einzel lens. The electric field is low in this region, even though the einzel lens is at 24 kV potential relative to surrounding injector components.

A low-cost, moderate intensity, and compact source of 750 keV protons now seems obtainable.

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