MECHANICAL ENGINEERING OF A 75-keV PROTON INJECTOR‡ FOR THE LOW ENERGY DEMONSTRATION ACCELERATOR

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Abstract

A dc injector capable of 75-keV, 110-mA proton beam operation is under development for the Low Energy Demonstration Accelerator (LEDA) project at Los Alamos. The injector uses a dc microwave proton source which has demonstrated 98% beam availability while operating at design parameters. A high-voltage isolation transformer is avoided by locating all ion source power supplies and controls at ground potential. The low-energy beam transport system (LEBT) uses two solenoid focusing and two steering magnets for beam matching and centroid control at the RFQ matchpoint. This paper will discuss proton source microwave window design, H_2 gas flow control, vacuum considerations, LEBT design, and an iris for beam current control.

1 INTRODUCTION

At Los Alamos, the cw LEDA radio frequency quadrupole (RFQ) accelerator[1] has been designed to produce a 100-mA, 6.7 MeV beam from a 75-keV, 110-mA dc proton injector beam. Design of the LEDA proton injector originated at Los Alamos in late 1993 when a prototype injector was designed and subsequently fabricated. This injector comprises a dc proton source and a dual solenoid low-energy beam transport (LEBT) system which has been extensively tested and found to deliver LEDA RFQ quality beams[2]. A LEBT, suitable for flexible beam matching to the LEDA RFQ, will first be tested with a 1.25 MeV cw RFQ brought from Chalk River Laboratories (CRL)[3]. In following sections, we present the mechanical design features of the proton source and accelerating column, injector reliability development, discussion of a 2.5-m-long LEBT for initial operation of the LEDA RFQ, and a final 2.8-m-long LEDA LEBT which incorporates beam duty factor control.

2 PROTON SOURCE AND ACCEL COLUMN

The microwave proton source, originally developed at CRL[4] for the 50-keV Chalk River Injector Test Stand (CRITS), has been further developed to operate at higher beam energy, current, and microwave power. Figure 1 illustrates the configuration of the ion source, new high voltage (HV) column, solenoid magnet insulator, and

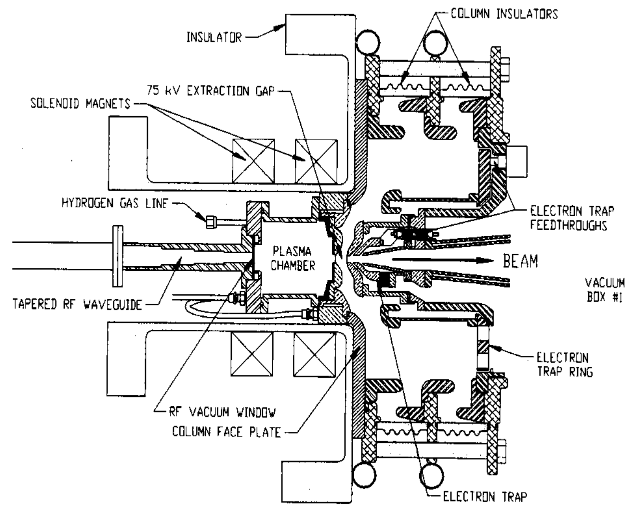

Figure 1. LEDA proton source and HV column.

extraction geometry. Figure 2 shows an exploded view of the microwave vacuum window assembly. All source electronics operate at ground potential, and beam extraction is across a single 75 kV gap. Extraction geometry is based on the Fusion Materials Irradiation Test (FMIT)[5] accelerator extractor. The extractor electron trap at -1.5 kV prevents backstreaming electrons from reaching the source. A ground potential electrode then terminates electric fields thus establishing beam space- charge neutralization.

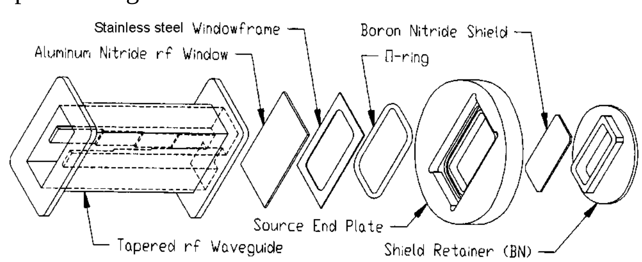

Figure 2. LEDA proton source microwave window.

Figure 3 shows the gas flow control system with a mass flow controller at ground potential. A variable leak valve keeps the pressure in the tube near atmospheric to

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prevent arcdowns through the tube. System response is a function of gas flow rate, pressure, and volume between the flow controller and variable leak valve. Use of a

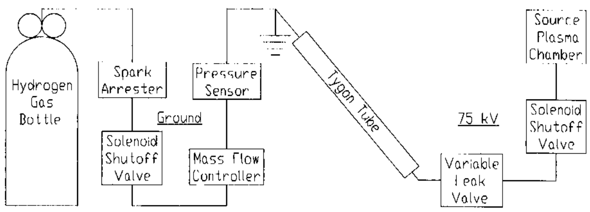

Figure 3. Gas flow control for the LEDA ion source.

pressure sensor having an internal volume of only 0.1 cm^3 enabled a minimum 3 cm^3 test system volume. For a step change between 0.095 and 0.101 T-l/s, the test system achieved an average time constant of 17.5s. The more complex gas system in use on the LEDA ion source has an approximate 6 cm^3 volume, but normally operates at 0.05 T-l/s resulting in approximately the same time response as the test system.

The HV column insulators are 95% alumina, and are vacuum sealed by o-rings under compression by 12 cryogenic grade G-10 rods. Internal vacuum-ceramic-metal electron emitting "triple points" are shielded by stainless steel inserts. Average beam power density in the nominal 4 cm diameter beam is 775 watts/cm^2; cooling protects internal vacuum system components from heating by spilled beam. A 100 mA proton beam current causes a 0.01 T-l/s gas load at a beam stop, and the hydrogen gas flow may be up to 0.09 T-l/s during source start up. Vacuum pumping of the HV column region is through a circular electron trap plate into diagnostics/vacuum box #1 equipped with a 2500 l/s turbomolecular pump.

3 INJECTOR RELIABILITY DEVELOPMENT

Two failure mechanisms of microwave window have been observed: (1) failure of the o-ring seal after less than 40 hours of operation, and (2) thermal fracture of the aluminum nitride (AlN) window. Failure mode (1) may arise from microwave and/or ion source-plasma induced heating of the o-ring. A solution was found by adding a 0.8mm thick stainless steel frame glued to the AlN window. Use of a pressure jig ensures an intimate Torr Seal bond between the stainless and AlN. Tight assembly tolerances then result in a metal to metal seal surrounding the o-ring (cf Fig. 2). The microwave window is now capable of indefinite operation at greater than 1 kW microwave power.

Rf window failure mode (2) is a product of operation at higher beam energies. Proton source rf efficiency is highest with a single AlN microwave window; however, back streaming electrons focused by the solenoidal field impact on a small point (approximately 1mm diameter) in the center of the window. Stress in the pinhole from electron impingement after an arc down can result in fracture of the AlN. A 1.3 mm thick pane of boron nitride (BN) shields the AlN window and does not measurably reduce the rf efficiency. The pinhole erosion rate is a function of mA-hours, and the 1.3 mm thick shield is expected to have a 400 hour lifetime under operating conditions. Tests are underway to further this lifetime by increasing the BN thickness, and investigating the use of Shapal SH-15 AlN (with excellent strength in compression and over three times the thermal conductivity of BN).

Initial operation of the new HV column was compromised by an unacceptable arcdown rate. External arcing problems were eliminated by modifications to the solenoid magnet insulator, a new solenoid magnet stand, addition of corona rings, a revised G-10 compression rod design, and careful routing of the water resistor lines. Internal arcing was eliminated by moving the extractor electron trap voltage feedthrough to a position within the extractor assembly. However, this relocation caused a glow discharge to occur near the extraction gap which unacceptably hindered injector operation.

Elimination of the glow discharge was successively accomplished by (1) reducing the magnetic field across the extraction gap by installation of an iron HV column face plate, (2) shielding the "triple points" from beam-produced x-rays, (3) improving the vacuum in the extraction gap by a new electron trap ring which increased the vacuum conductance by a measured factor of 3.2 (vs. a calculated factor of 4.1), and (4) modifying electron trajectories toward the extraction gap by an electron trap shield around the extractor.

During injector testing, an oil contamination incident occurred. Because of a control system problem, the roughing line valve to vacuum box #1 began to repeatedly cycle and introduced a large amount of rough pump oil into the vacuum box. Residual gas analysis indicated that conventional cleaning techniques did not remove all the oil contaminant, and a complete disassembly of the vacuum box would be necessary unless another decontamination method were found. After operation of the source with an oxygen beam (less than 6 hours total run time), residual gas analysis showed the oil was reduced. An oil-free scroll roughing pump has been installed to ensure the injector remains oil free.

4 INJECTOR LEBT

For initial operation of the LEDA RFQ, a 2.5-m-long LEBT is being assembled. This LEBT will be tested with the 1.25 MeV cw CRITS RFQ and includes the present injector vacuum box #1, twin LEBT solenoid magnets, vacuum box #2 which contains a copper-swirl-tube plunging beam stop, and a small diagnostics box at the RFQ entrance. This LEBT will be fitted with a variable iris (Figure 4) for beam current control. Eight internally-cooled, flat copper plates form the iris. As the drive ring is rotated, a camming action causes the iris aperture to vary. The flat plate design and copper construction limits the power absorption capability of the iris, but we estimate the life of the iris as adequate for tests with the CRITS RFQ and initial operation of the LEDA RFQ.

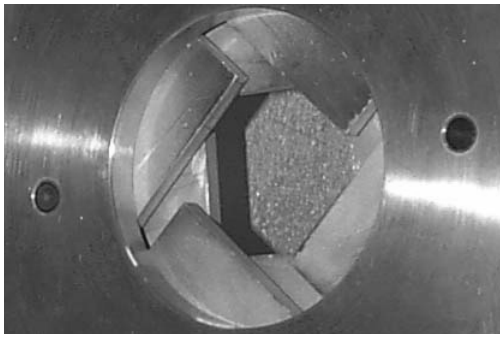

Figure 4. Beam iris developed for the LEDA LEBT.

Figure 5 shows a final 2.8-m-long LEDA LEBT[6]. A pulsed beam is required for LEDA RFQ commissioning tests, and two techniques for doing this are being investigated. This LEBT incorporates a kicker magnet to provide the capability to produce a pulsed beam. Vacuum box #2 provides the required drift length for the angled beam to hit the retracted beam stop. The plunging beam stop and beam iris are projected to have inclined faces of molybdenum and be capable of long operational life. Vacuum box #3 will be a mounted on the LEDA RFQ, and accommodates beam diagnostics, beam shields, an isolation valve to the RFQ, and a 1100 l/s turbomolecular pump.

5 CONCLUSIONS

Integrating the mechanical design features outlined above enabled a 168 hour endurance run (total run time excluding delays from electronic problems). This injector test met the LEDA beam availability requirement, and demonstrated a robust design. Table 1 shows the injector is capable of producing a proton beam of requisite quality for the LEDA RFQ. The first 2.5-m-long LEDA LEBT will be tested in mid-1997 and be ready for operation with the LEDA RFQ in early 1998.

Table 1. Summary of LEDA injector requirements and present status.

Parameter	Required	Status
Energy (keV)	75	75
Current (mA)	110	117
Duty factor (dc)	100	100
Duty factor (pulsed) (%)	1 (10Hz, 1 ms)	To be tested
Reliability (%)	98	96 - 98
Lifetime (hr)	>168	168
LEBT exit emittance (πmm-mrad)	0.20	0.20
H_2 gas flow (T-l/s)	.04 -.10	.05-.09

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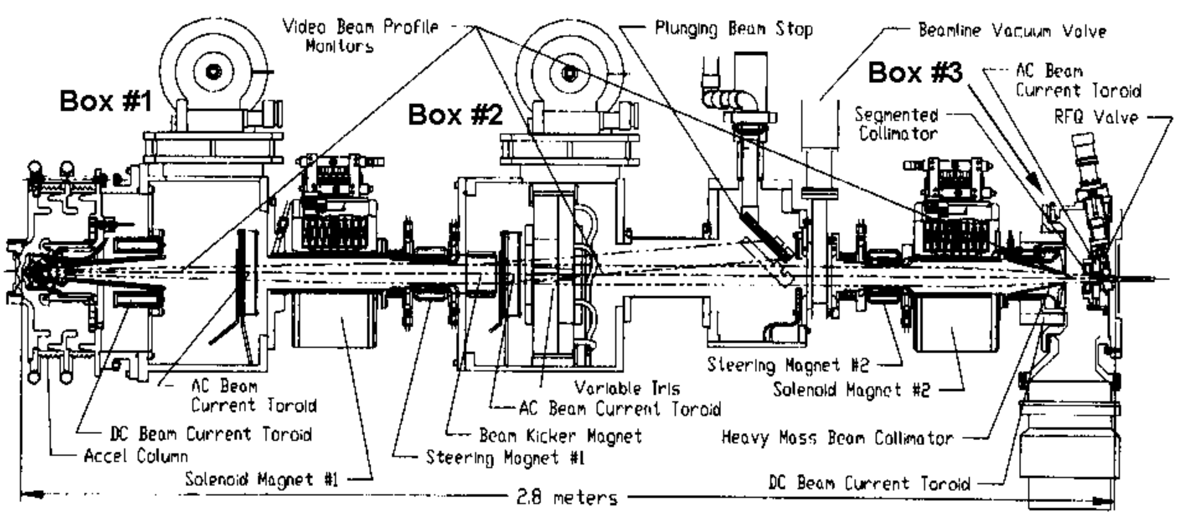

Figure 5. 2.8 m long LEDA LEBT.