LIFETIME TEST ON A HIGH-PERFORMANCE DC MICROWAVE PROTON SOURCE[*]

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Powerful CW proton linear accelerators (100 mA at 0.5 - 1 GeV) are being proposed for spallation neutron source applications. These production accelerators require high availability and reliability. A microwave proton source, which has already demonstrated several key beam requirements, was operated for one week (170 hours) in a dc mode to test the reliability and lifetime of its plasma generator. The source was operated with 570 W of microwave (2.45 GHz) discharge power and with a 47-kV extraction voltage. This choice of operating parameters gave a proton current density of 250-mA/cm^2 at 83% proton fraction, which is sufficient for a conservative dc injector design. The beam current was 60 - 65 mA over most of the week, and was sufficiently focused for RFQ injection. Total beam availability, defined as 47-keV beam-on time divided by elapsed time, was 96.2%. Spark downs in the high voltage column and a gas flow control problem caused all the downtime; no plasma generator failures were observed.

I. INTRODUCTION

Several new applications for high-power proton linacs are being proposed [1] for spallation neutron sources with nuclear processing applications such as transmutation of nuclear waste and the production of tritium. Proton injector requirements for these linacs have been summarized [2], and, for radio frequency quadrupole (RFQ) injection, parameters are typically 110-mA proton-beam current at 75 keV. At these beam parameters the ion source reliability and longevity become difficult. One MW accelerators at Villigen, Switzerland and Los Alamos, New Mexico use a dc filament-driven volume source [3] and a pulsed duoplasmatron [4] to deliver the required proton currents. The basic technology accelerator (BTA) in Japan [5] is using a filament-driven volume source.

A microwave proton source [6] has been chosen for the dc ion source at Los Alamos for the high-intensity linac injector. Its higher-power efficiency and lower H$_2$ gas consumption [2] suggest it may be a more reliable, longer-lived proton source. Long lifetime electron-cyclotron resonance (ECR) oxygen ion sources similar to this microwave proton source have been reported [7]. This paper reports on a 170 hour continuous run in which the microwave source produced 60 - 65 mA hydrogen-ion current at 47 keV without a plasma-chamber fault.

II. EXPERIMENT

This experiment was performed on the 50-keV injector brought from Chalk River Laboratories (CRL) to Los Alamos. The microwave proton source power supplies operate at ground potential except for the gas-flow controller which is powered through a small isolation transformer. Figure 1 shows the ion-source and accelerating-column installation at Los Alamos [8]. As configured, this injector cannot meet the energy and current requirements of the proposed CW linacs; an advanced injector to meet these requirements has been designed [2], and is now undergoing tests at Los Alamos.

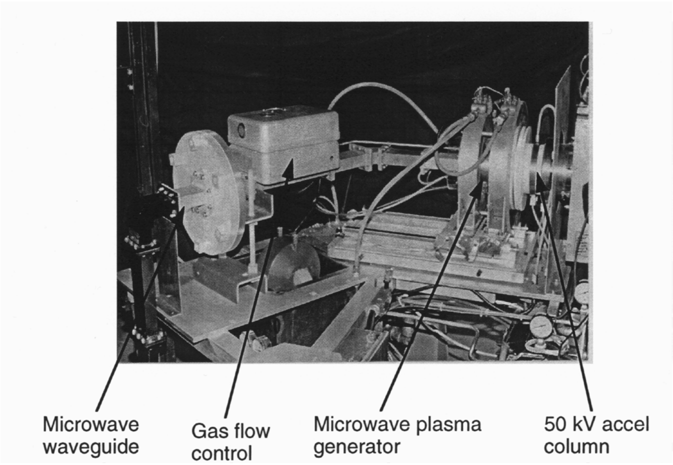

Figure 1. Installation of the 50-keV injector at Los Alamos. Locations for the 2.45-GHz microwave waveguide, the gas-flow controller, the microwave plasma generator, and the 50-keV accel column are shown in the picture. The isolation transformer is located immediately under the gas-flow controller.

The 47-keV extraction voltage was chosen to provide a well-focused beam with > 200-mA/cm^2 proton current density. The advanced injector would attain the required 110-mA proton current through a 4.2-mm radius emission aperture at 200 mA/cm^2 current density. The present experiment was operated with > 60-mA hydrogen-ion current extracted through a r_e = 2.5-mm radius emission aperture. The 83% proton beam fraction measured at the conclusion of the seven-day run is shown in Fig. 2. The proton current density $j_p = (60\ \mathrm{mA})(0.83)/(\pi r_e^2) = 250$ mA/cm^2 thus exceeds the advanced injector design requirement by 25%. The ion source was run with 570 W forward power with 1 - 10 W reflected power at the 2.45 GHz operating frequency. The H$_2$ gas flow was 2.7 sccm, which implies 13% efficiency for conversion of H$_2$ gas into proton beam current. The 47-keV hydrogen-ion beam was dumped on a watercooled copper beam stop. Taking the copper sputtering coefficient $S = 3.7 \times 10^{-3}$ atoms/ion and a 1 cm beam radius, a beam dump lifetime of 274 days was

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calculated. No beam dump problems were encountered over this seven day run.

During preparation for the seven-day longevity test, a problem with the O-ring seal at the microwave window was encountered. The vacuum interface between the WR284 waveguide and plasma chamber is formed by a 2-mm thick piece of aluminum nitride (AlN) which compresses an O-ring seated in the back wall of the plasma chamber. During earlier discharge operation, this O-ring failed unpredictably. The problem was solved by installing a 0.025-mm metal sheet at the AlN window-O-ring interface, where it does not interfere with the microwave transmission into the plasma chamber. This failure mode was apparently unique to our operation, as others [9] working with this proton source have not encountered this problem.

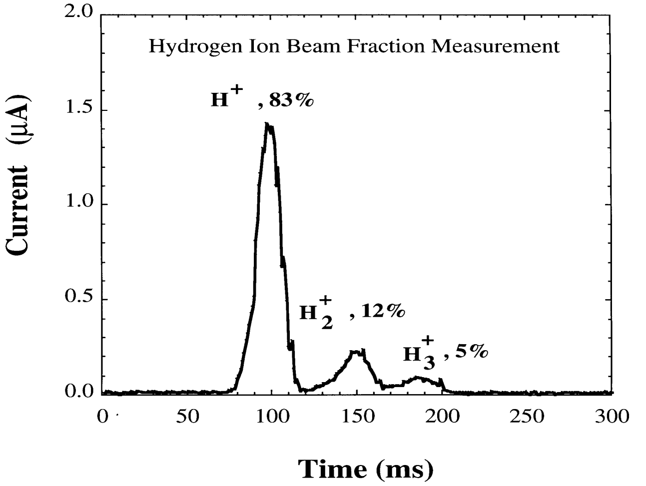

Figure 2. Hydrogen-ion beam fractions measured at the conclusion of the seven day run. The beam-fraction diagnostic uses a massively cooled 0.15-mm slit, a ramped magnetic dipole field, and a collector cup which samples the separated hydrogen-ion currents.

III. RESULTS

A. Ion Source Availability and Longevity Test

Figure 3 shows the beam availability as a function of the elapsed time. Beam availability is defined as the 47-keV beam on time divided by elapsed clock time. During the first 24 hours of operation significant downtime was encountered because of gas-flow instabilities brought about by rising temperature in the confined high-voltage (HV) area (see Fig. 1). This problem was overcome by installing fans on the HV enclosure to circulate the stagnant air. From 24:00 hours onward, the beam availability increased continuously to 96.2% at the end of the seven-day period. Most of this 4% downtime was spent recovering from HV sparks in the HV column. The average recovery time from a beam-off event was 83 seconds, which is dominated by the resetting of the HV power supply to the extraction potential. The longest uninterrupted run time was five hours. After completion of the seven day run, the ion source was inspected for wear or imminent component failure. No obvious signs of wear were found, and it is unknown how long the source would have run before failing. The ion source longevity is now demonstrated to be greater than 170 hours.

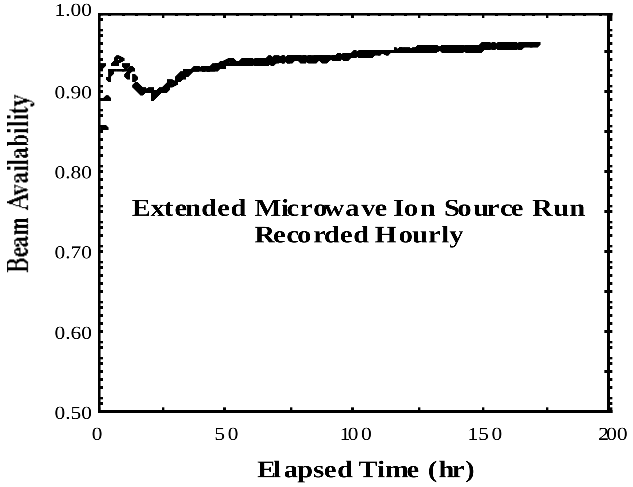

Figure 3. Beam availability vs. elapsed time curve. Beam availability is defined as the 47 keV beam-on time divided by the elapsed clock time.

B. Beam Emittance Measurement

Previous proton emittance measurements have been made with the microwave ion source only [6] and ion source plus single-solenoid low energy beam transport (LEBT) [10] for 50 keV, 60 - 70-mA beams. The ion source-only results give rms normalized emittances in the 0.10 - 0.12 (πmm-mrad) range while the ion source plus LEBT measurements yield 0.20 (πmm-mrad). The LEBT measurements relied on a Gaussian extrapolation procedure to eliminate the H_2^+ and H_3^+ components, which is a reasonable approach because the hydrogen ion beam was dominated by the 75% proton fraction.

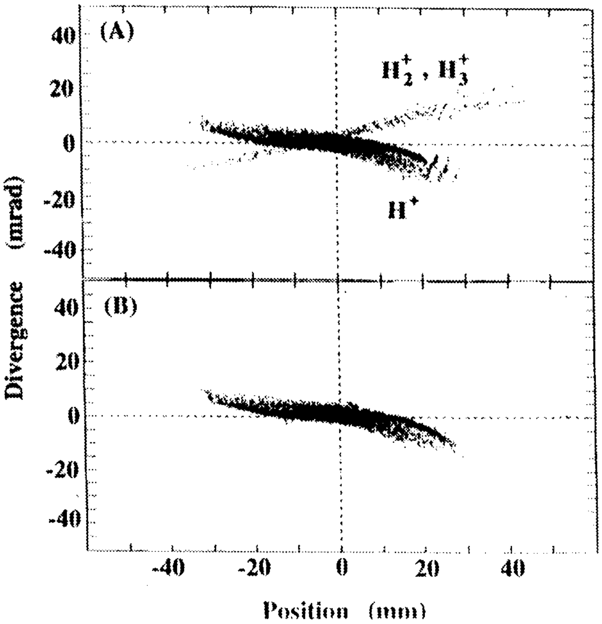

Figure 4. (A) Hydrogen-ion beam distribution after transport through a single-solenoid LEBT. (B) The same distribution as (A) but with the H_2^+ and H_3^+ species removed.

Table 1. Requirements and status of demonstrated injector parameters for 100-mA CW linac program.

Injector Parameter:	**Requirement:**	**Observed:**
Beam Availability (%)	>98	96.2
Minimum ion source lifetime (hours)	>160	>170
Beam energy (keV)	75	47
Beam current, protons (mA)	110	50
Proton beam current density (mA/cm^2)	200	250
Beam emittance (πmm-mrad), rms normalized @ 110 mA, 75 keV. RFQ injection.	0.20	0.20 @ 50 keV, 56 mA, through a single-solenoid LEBT.

The LEBT emittance data in ref. [10] have now been reanalyzed by removing the H_2^+ and H_3^+ contributions to the measured phase-space distribution. An original distribution is shown in Fig. 4(A) where the main proton distribution plus the H_2^+ and H_3^+ components are separated by the magnetic field of the focusing solenoid. The distribution in Fig. 4(B) shows the same datafile with the H_2^+ and H_3^+ components removed. Analysis of the Fig. 4(B) distribution in terms of beam fraction vs. total emittance [11] gave 0.20 (πmm-mrad) proton beam emittance for 100% beam fraction, which agrees with results presented in ref. [10].

IV. SUMMARY

LANL proposals for 100-mA CW linacs have a RFQ [1] as the first rf acceleration stage, and the RFQ sets injector parameters. The injector parameters and requirements are summarized in columns 1 and 2 of Table 1. A consistent set of observed microwave ion source/injector parameters is shown in column 3. The present ion source results exceed the ion source lifetime and beam current density requirements, and is close to meeting the beam availability requirement. During a 170 hour run, 47-keV beam was available for 96.2% of the elapsed time. Most of the beam off time came from HV column sparkdown recovery, and it is anticipated that the > 98% specification can be achieved with an optimized column design and high-voltage power supply. No plasma generator failures were observed over the 170 hours.

Greater than 50-mA proton current was maintained over the 170 hours. This parameter needs to be doubled for the CW linac applications. The observed 250-mA/cm^2 proton current density exceeds the advanced injector design requirement [2] by 25%. An increase in proton current, at a constant discharge power, is likely from the work at Argonne National Lab and Los Alamos [12] where proton beam fractions > 90% have been measured from the microwave source. The beam energy needs to be increased 60% from 47 to 75 keV.

Proton beam emittance of 0.20 (πmm-mrad) rms normalized, has been inferred from hydrogen ion beam emittance measurements through a single-solenoid LEBT [10]. The inferred 0.20 (πmm-mrad) emittance has been confirmed here by analysis of a datafile with the H_2^+ and H_3^+ species removed. Maintaining the required proton beam emittance at the RFQ injection point while increasing the proton current and energy may be the most severe remaining technical injector challenge. The advanced 75-keV injector design, based on the microwave proton source, for 110-mA proton current at 75 keV is now under development at Los Alamos to address these questions.

V. ACKNOWLEDGEMENTS

We thank Chalk River Laboratories, Ontario, Canada, for transferring the microwave proton source technology and 50-keV injector to Los Alamos. With this help, LANL has been able to make good progress towards demonstrating a proton injector for the 100-mA CW linac programs.

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