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A DC PROTON INJECTOR FOR USE IN HIGH-CURRENT CW LINACS

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Abstract

A 75-keV dc and pulsed-mode proton injector is being developed for beam testing of a 100-mA, 6.7-MeV cw radio frequency quadrupole (RFQ) at Los Alamos. A microwave proton source operating at 2.45 GHz produces 130-mA hydrogen-ion beam currents with >85% proton fraction, yielding the 110-mA proton current required at the RFQ injection point. Doppler-shift spectroscopy confirms previously measured proton fractions. The discharge may be pulsed by current modulation of the magnetron power supply. A 1-MHz coherent oscillation observed in the extracted ion beam was eliminated by selecting proper magnetron operation. Transport and matching of the proton beam to the RFQ is accomplished by a two-solenoid, beam space-charge neutralized low-energy beam transport (LEBT) system. The injector was temporarily reconfigured to operate at 50 keV for injector matching studies into a 1.25 MeV cw RFQ. A maximum current of 100-mA has been accelerated through the RFQ in cw mode.

1 Introduction

Linear accelerator projects are being proposed for generating high-current (100 mA) and high-energy (1 GeV) proton beams[1]. A high-energy RFQ (6.7-MeV output energy) and a coupled-cavity drift-tube linac (CCDTL) section are proposed for injection into a coupled-cavity linac structure[2]. To ensure successful linac testing, a reliable, flexible, and high-performance proton injector is required. Most of the dc injector 75-keV beam qualities have been demonstrated[3]. Further progress on this proton injector is reported here.

Recent ion-source advances are summarized in section 2. Section 3 describes a test of the injector's low-energy beam transport (LEBT) concepts on a 1.25-MeV cw RFQ originally developed at CRL[4], and subsequently moved to Los Alamos for test purposes[5].

2 Ion Source Development

Previous proton-fraction measurements have been made by magnetic-field analysis of beam sections[3]. The microwave proton source[3,6] used in this injector produces the H^+, H_2^+, and H_3^+ ions extracted at energy, E, from the plasma. A technique developed for the magnetic fusion community[7] is used to deduce the proton fraction by measuring the light intensity of the Doppler-shifted Balmer alpha transition. The origin of the different velocity H^0 arises from neutralization and disassociation reactions of the hydrogen-ion beam species on the background gas in the injector LEBT system. The largest Doppler shift occurs for $H^0(E)$ from H^+, and then reduced Doppler shifts from Balmer $H^0(E/2)$ and $H^0(E/3)$ corresponding to H_2^+ and H_3^+. An example of this measurement using the Balmer alpha (n=3 to 2) transition at 656.2 nm is shown in Fig. 1 for a hydrogen ion beam energy of E = 50 keV. The peak corresponding to the plasma H^0 is not shifted, but the light peaks corresponding to the hydrogen-ion beam are shifted to shorter wavelengths because the observations are made in the forward direction, approximately 60^0 from the beam direction. The Doppler shift between the light peaks corresponding to the plasma and H^+ beam H^0 emissions is approximately 3 nm. Analysis of this data requires

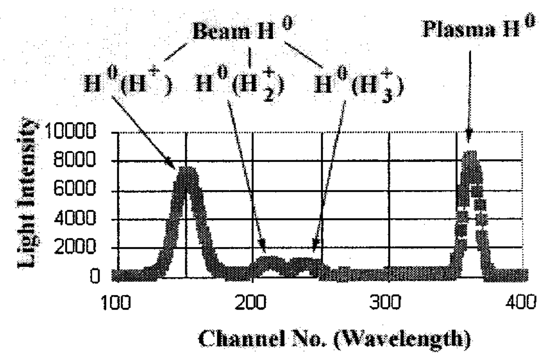

Figure 1. Doppler-shift proton beam fraction data for a 50-keV hydrogen-ion beam.

knowledge of the Balmer-α production cross sections[8] on the background H_2 gas, and results in a beam composition of 90% H^+, 6%H_2^+, and 4% H_3^+. This is in agreement with the earlier magnetic field analysis[3].

Injector-beam measurements[3] using an ac toroid with 10-MHz bandwidth revealed that the beam frequently had a 1-MHz oscillation which could be tuned away by judicious choice of ion-source operating parameters. If the amplitude of such oscillations is sufficiently large, beam-transport instabilities may develop in LEBTs relying on beam space-charge neutralization[9]. Spectrum analysis of the magnetron tube which provides power at 2.45 GHz to the hydrogen plasma discharge revealed 1-MHz sidebands when the magnetron is operating in the 600 - 800 W range, where the appropriate plasma densities for creation of 130-mA injector beam currents are found. Figure 2 shows the power level measured for the magnetron and the ac toroid plotted vs. frequency at 680 W magnetron tube output power. Here the zero frequency on the ac toroid beam noise measurement has been adjusted to match the center frequency of the magnetron near 2453 MHz. The beam-current oscillations at 1 MHz and its higher harmonics line up strikingly well with the magnetron sideband frequencies. Further investigations[10] showed that the magnetron power spectrum is free of sidebands at 975 W. Installing a -1.78 dB attenuator in the 2.45GHz waveguide

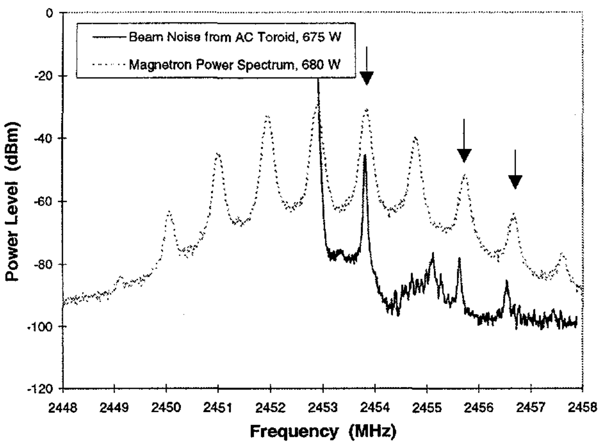

Figure 2. Comparison of the magnetron sideband frequencies operating at 680 W with the beam current oscillation frequencies observed in the ac toroid beam current diagnostic.

between the magnetron and ion source made it possible to operate the magnetron in the 1000 W range while delivering 680 W to the ion source. The 1-MHz beam noise was reduced -30 dB while using this microwave power delivery system[10].

Linac commissioning and fast-protect are additional responsibilities required of the injector. Linac commissioning will occur in two modes: reduced duty-factor (df) high-current mode and low current cw mode. A commonly discussed high-power linac option is 100 mA beam current at 1 GeV which corresponds to 100 MW beam power. A goal given to the injector is to turn the beam off in < 10 μs. The first method chosen to turn the beam off is to install a fast voltage modulator capable of delivering up to -5 kV to the magnetron tube cathode where the delivered current is regulated to < 1%. Such a device has been built[11] and tested on the proton injector. The beam-current measurement was made on a dc beam stop with magnetic secondary electron suppression. The device df varies from <0.01% (100 μs pulse length, 1 Hz)

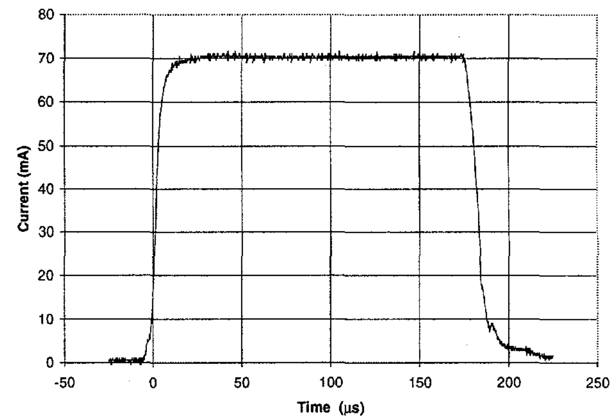

Figure 3. Hydrogen-ion beam pulse. The beam pulse was generated by pulsing the hydrogen discharge with a current-regulated voltage pulse to the magnetron cathode.

to dc. Figure 3 shows a 200 μs long 70-mA beam pulse. The time scale is 50 μs per major division, and the rise and fall times are seen to meet the 10 μs requirement.

3 Injector Test on a 1.25 MeV cw RFQ

The LEBT system chosen to transport the ion source beam to the RFQ is a magnetic two-solenoid focus system which relies on the beam's space-charge being neutralized by electrons originating via beam-background gas ionization. This LEBT concept is chosen because of its demonstrated success and flexible beam matching capabilities into RFQs[12]. Earlier measurements showed that the proton beam's space charge is 98% canceled by electron accumulation in the beam potential well[13]. With this compensation degree, a two-solenoid magnetic LEBT properly matches the beam into an RFQ.

A test of these injector concepts has been carried out on a cw 1.25-MeV RFQ[4,5]. This integrated test used two solenoid magnets for RFQ transverse phase-space matching, and two steering magnets to position the beam at the RFQ entrance. The LEBT length is 2.5 m, and has all of the functionality of the 2.8 m LEBT discussed in ref. 3 except the fast beam kicker. The 75-keV tetrode extraction system was modified to a 50-keV triode extractor. The injector also includes dc beam current monitors at the ion source exit (DC1) and midway in the LEBT between the two solenoids (DC2). Beam profile and position monitoring is accomplished by two video diagnostic stations, again located at the ion source exit and midway through the LEBT after the first solenoid.

The basic 1.25-MeV RFQ design parameters are listed in ref. [4]. The primary diagnostic in the RFQ measurement was a third dc beam current monitor (DC3) located at the RFQ exit. The RFQ transmission (%) is 100(DC3/DC2). The location of DC2 is not optimal: it would be preferable to have DC2 at the RFQ entrance. The present DC2 location leads to an overestimate of the

RFQ input current which results in a lower-than-actual RFQ transmission.

On several occasions the RFQ design current of 75 mA was routinely reached. The RFQ current measurement (DC3) was checked by calorimetric measurements on the cw beam stop, and the agreement is < ±6%. Systematic search of LEBT solenoids one and two led to the data shown in the contour plot of Fig. 4. Here the contour lines represent equal transmission in the

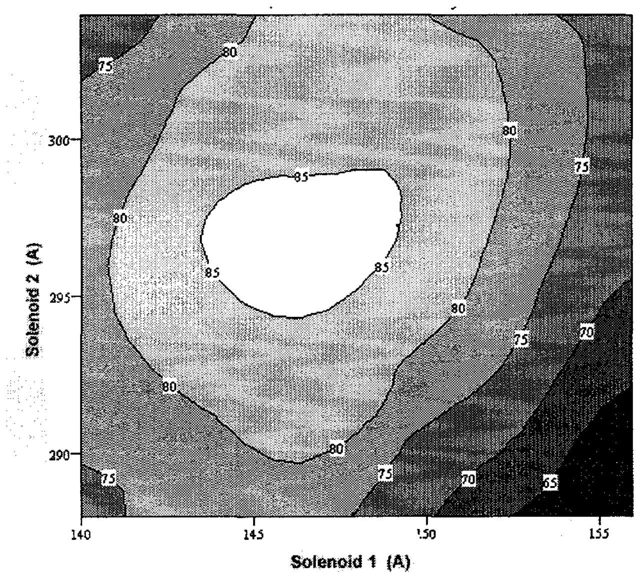

Figure 4. Contour plot of beam current transmission through the 1.25 MeV RFQ as a function of the LEBT solenoid one and two currents. LEBT solenoid one is located upstream, closest to the ion source. At 85% transmission, the RFQ is operating at the 75 mA design current value.

solenoid tuning space. At the 75-mA RFQ design current, measured transmissions are 80-85%. On one occasion, while attempting to establish the maximum RFQ current, 100 mA was observed in DC3. This high-current operation (25 mA above design, cf. ref. [4]) was limited by the injector's ability to deliver proton current to the RFQ , and limitations on rf power delivered to the RFQ.

Acknowledgments

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