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Author(s):

T. Zaugg, C. Rose, J.D. Schneider, J. Sherman, R. Stevens, Jr. (LANL, Los Alamos, NM)

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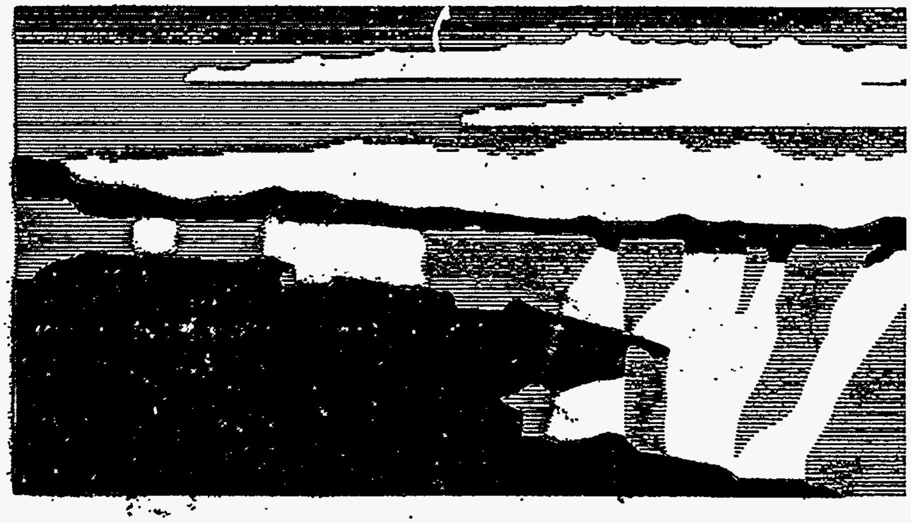

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Operation of a Microwave Proton Source in Pulsed Mode[*]

T. ZAUGG, C. ROSE, J. D. SCHNEIDER, J. SHERMAN, R. STEVENS, Jr.
Los Alamos National Laboratory, Los Alamos, NM 87545

Abstract

Initial beam operation of the cw radio-frequency-quadrupole (RFQ) built for the Low Energy Demonstration Accelerator (LEDA) project requires the injection into the RFQ of a 75-keV, pulsed, H^+ beam with a rise and fall time less than 10 microseconds and a pulse width from 0.1 to 1 millisecond at a repetition rate up to 10 Hz. The ion source for the accelerator is a microwave proton source driven by a 2.45-GHz magnetron. Pulsed beam for the RFQ is accomplished by modulation of the magnetron tube current. The magnetron provides microwave pulses to the ion source, and a medium-bandwidth, extraction power supply produces the H^+ ion beam using a four-electrode extractor. A similar ion source with a three-element extractor operating at 50 kV has also been tested with this magnetron modulator. We report the results of modulating the ion-source microwave power and extracting a pulsed proton beam using both a triode and a tetrode extractor.

1 INTRODUCTION

The LEDA accelerator [1] is being constructed to test and verify critical accelerating components that will be part of the Accelerator Production of Tritium (APT) plant facility. A line drawing of the LEDA ion source and extraction region is shown in Figure 1. The 75-keV injector [2] for the LEDA accelerator consists of a microwave source, a tetrode extractor and a low-energy-beam-transport (LEBT) [3] that includes two solenoid magnets. A magnetron provides 500 to 700 watts of microwave power to the ion-source plasma chamber. Two solenoid magnets in the injector produce an axial magnetic field of approximately 875 gauss to create an electron-cyclotron-resonance condition in the plasma chamber. The four elements of the tetrode extractor are the ion-source aperture electrode at 75-kV, the extraction electrode at ground, the electron suppressor electrode at -1.5-kV and a second ground electrode used to quickly establish beam neutralization.

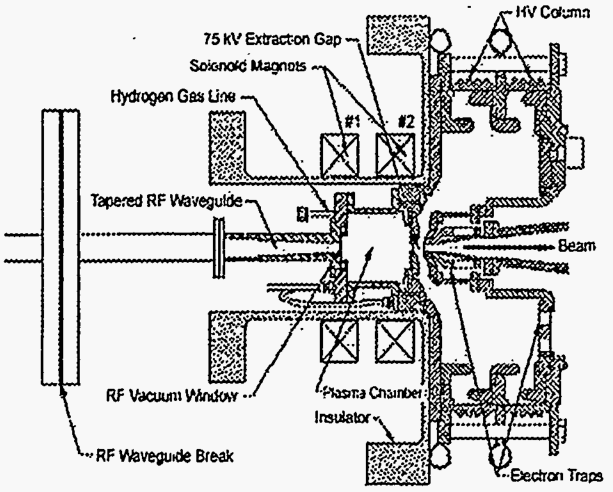

Figure 1. LEDA microwave proton source.

The current from the extraction power supply is sampled by a Pearson transformer (I_{ps}). Low-frequency components of the beam current are measured using two parametric current transformers (PCT) [4], one at the exit of the ion source (PCT1) and the second between the two solenoid magnets of the LEBT (PCT2). An ac current transformer at the exit of the ion source measures the high-frequency beam-current components. A beam stop, known as the plunging beam stop, can be inserted into the beamline between the solenoid magnets of the LEBT and also provides a means of measuring beam current (I_{pbs}).

Although dc (100% duty factor) operation is the normal operating mode, initial beam testing will be done in pulsed-mode conditions. This pulsed-mode, low-duty-factor operation is necessary to minimize equipment damage during beam impingement. The ion-source pulsing described herein is our preferred means of accomplishing this mode of operation.

2 MODULATOR DESIGN

A sketch of the magnetron modulator [5] is shown in Figure 2. A dc set point value for the desired magnetron

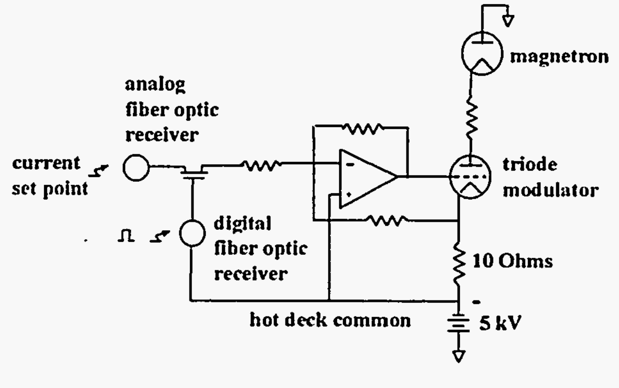

Figure 2. Magnetron current-modulator diagram.

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current is compared to the voltage developed across the modulator tube's cathode resistor. The modulator acts as a current source that sets the magnetron current to zero when the digital pulse is not present and controls the magnetron current to a value determined by the set point when the digital pulse is present. The modulator tube and the feedback components are raised to the hot-deck voltage set by the -5 kV power supply. Filament supplies for the magnetron and modulator also must be isolated at this voltage level.

Our magnetron is sensitive to cathode-to-anode voltage and generates full output power variation for a few hundred volts change in voltage. Our current-controlled modulator design takes advantage of the more linear power response characteristics of the magnetron as the tube current is varied. Figure 3 shows the typical linearity of magnetron output power versus magnetron current when the magnetron is controlled by the current modulator.

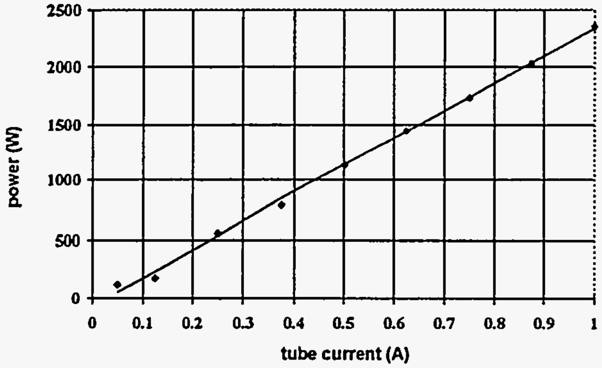

Figure 3. Microwave power versus tube current.

The output power is measured using a waveguide-directional-coupler and a calibrated diode with an error less than 0.5-db over the range of 500 W to 2500W.

3 PULSED OPERATION OF THE LEDA INJECTOR

Figure 4 shows the leading edge of the extracted beam current from the LEDA injector when the magnetron is producing a 750-W pulse. The limited bandwidths (4 kHz for PCT1 and 20 kHz for PCT2) of the two parametric current transformer devices are evident in the delayed and relatively slow risetimes seen for these two signals. Displayed difference in measured current for PCT1 and PCT2 is typical for this injector and reflects the beam-transport characteristics of the LEBT. The ac beamline transformer has a bandwidth greater than 10 MHz and droop of approximately 0.4%/µsec for a square wave of current. The plunging-beam- stop current measurement nearly equals the PCT2 measurement. (PCT2 and I_{pbs} are located close together on the beamline.)

A set of oscilloscope traces of these same five signals on the trailing edge of a 1 ms pulse is shown in Figure 5.

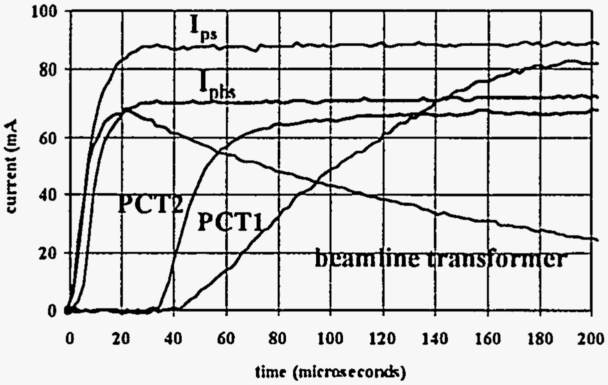

Figure 4. Leading edge of the extracted current from the LEDA injector.

The beam current response time meets the specification required for RFQ commissioning.

Longer pulse lengths show a slight rise in current as the pulse length increases. A 10 ms pulse shows a 10% increase in the current from beginning to end of the pulse. This effect is believed to be due to temperature effects in the plasma chamber that cause the source characteristics to change The flattop response of the beam current is acceptable with the modulator loop controlled around the magnetron tube current, but an improved flattop response is likely if the loop is closed around the extracted beam current

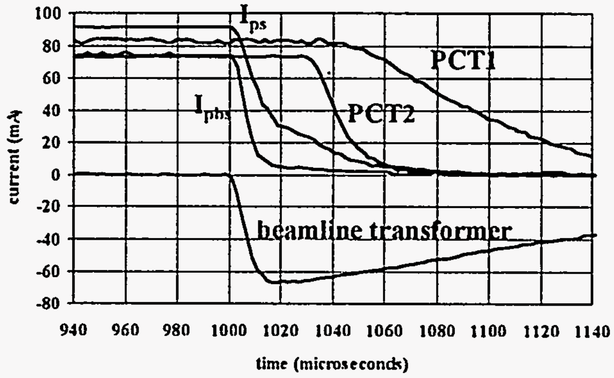

Figure 5. Trailing edge of the extracted current from the LEDA injector.

The effect of magnetron power on the extracted beam current can be seen in Figure 6. Measured values are averaged over 50 samples near the end of 1 ms pulses. The solid lines are second-order polynomial fits to the data points used only to focus the eye on the trend in the data. The extractor power-supply current (I_{ps}) and PCT1 current continue to rise with increasing input power but the PCT2 and I_{pbs} currents reach a maximum value and then fall off as beam transport is affected by the beam divergence from the source. (Standard CCD cameras are used to observe the transverse beam profile.) The measurements shown in Figure 6 were made without any other change in the ion-source settings; the ion-source was adjusted for best operation at a microwave power of 750-W. It should be noted that a single setting is not ideal for this broad range of power.

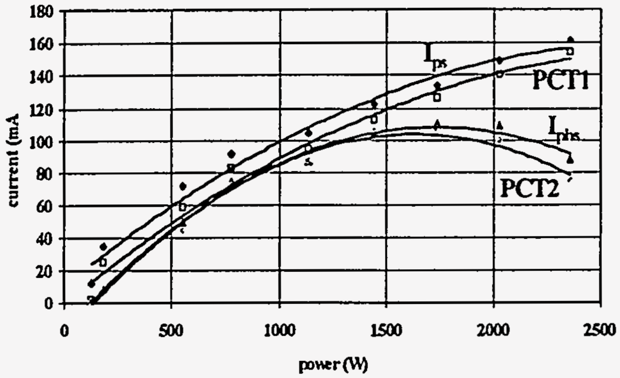

Figure 6. Beam current versus microwave power for the 75-kV tetrode extractor.

4 PULSED OPERATION OF THE TRIODE INJECTOR

The current- modulator was also tested on a 50 kV triode injector. The LEDA microwave injector was converted from a tetrode extractor to a triode extractor. (The three elements of the triode extractor are the ion-source aperture electrode at 50-kV, an accel-decel electrode at -2.0-kV and an electrode at ground.) This injector was used to deliver a dc beam to a cw, 1.25-MeV RFQ and was conveniently available for pulsed operation into the plunging beam stop.

The time-response of the extracted beam for this injector is dramatically different from that seen for the tetrode extractor. Figure 7 is a plot of I_{ps}, PCT1, PCT2 and I_{pbs} currents with a 100 r.s pulse. The extractor power supply initially supplies almost twice the current that is transported through the LEBT. Beamline current rises rapidly to about 10% of the final value and then slowly rises to its final value with a time constant of approximately 10 ms. No serious attempt has been made to discover why the extraction and transport response of the triode injector is so different from the tetrode injector. It is known that the electron suppressor voltage is not significantly affected and that electron production at the extractor electrode is not contributing to the problem.

5 SUMMARY

A linear, current-controlled magnetron modulator has been used to produce pulsed proton beams from a microwave ion source. The extracted beam from the tetrode injector produces acceptable pulsed beam for the LEDA RFQ. Use of this modulator on a triode extractor is less satisfactory since extraction and transport effects cause a slowly rising beam-current pulse. Similar pulsed-beam effects from a microwave source have been observed at the Saclay laboratory [6].

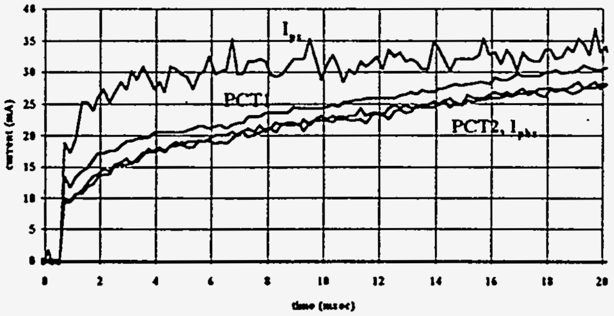

Figure 7. Leading edge of the beam current extracted from the 50-kV triode injector.

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