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PROTON BEAM STUDIES WITH A 1.25 MeV, CW RADIO FREQUENCY QUADRUPOLE LINAC*

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Abstract

A high-current, cw linear accelerator has been proposed as a spallation neutron source driver for tritium production. Key features of this accelerator are high current (100 mA), low emittance-growth beam propagation, cw operation, high efficiency, and minimal maintenance downtime. A 268 MHz, cw radio frequency quadrupole (RFQ) LINAC section and klystrode based rf system were obtained from the Chalk River Laboratories [1] and were previously installed at LANL [2] to support systems development and advanced studies in support of cw, proton accelerators. A variation of the Low Energy Demonstration Accelerator (LEDA) proton injector, modified to operate at 50 keV, was mated to the RFQ and was operated to support advance developments for the Accelerator Production of Tritium (APT) program. High current, proton beam studies were completed which focused on the details of injector-RFQ integration, development of beam diagnostics, development of operations procedures, and personnel and equipment safety systems integration. This development led to acceleration of up to 100 mA proton beam.

1 INTRODUCTION

The Chalk River Injector Test Stand (CRITS) was the LANL designation given to a proton accelerator designed, built, and tested at the Chalk River Laboratories (CRL) in Canada. The CRITS accelerator apparatus includes a 1.25 MeV RFQ accelerator section and a prototype klystrode-based rf system for powering the RFQ. An earlier independent study at LANL, utilizing the RFQ, focussed on the high-power operation of the rf structure [2].

The LEDA program has the objective of developing a high-current, cw injector and the initial rf accelerating structures for APT. The LEDA injector is comprised of the proton ion source and a Low Energy Beam Transport (LEBT) section to the RFQ. A 75 kV, cw proton ion source was developed for LEDA and has produced a proton beam with measured current and emittance meeting program requirements. A state-of-the-art LEBT was designed and built to match the ion source beam to the LEDA RFQ [3].

The functionality of an injector is best confirmed by injecting its beam into an RFQ. In preparation for installing the injector as a component of LEDA, the availability of the CRITS RFQ provided the opportunity for an initial shakedown of the injector. The modification of the ion source to 50 kV and adaptation of the LEBT exit section to the CRITS RFQ made the LEDA injector/CRITS RFQ configuration a realistic testbed for injector development. Furthermore, this configuration also supported RFQ experiments to evaluate the system modeling codes and to learn the details of cw RFQ operations. Figure 1 shows the full beamline used in this project.

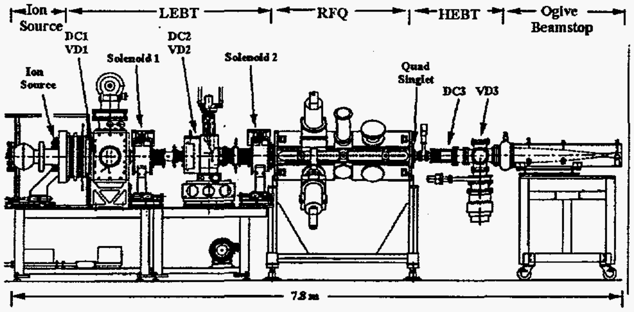

Figure 1. The LEDA Injector/CRITS RFQ experiment beamline.

In order to meet the project objectives, the RFQ specific studies focussed on verifying the RFQ field configuration, successfully operating the RFQ at high fields, verifying the accelerating fields in the RFQ, and accelerating proton beam from the modified LEDA injector.

2 RFQ FIELD DISTRIBUTIONS

Although the Q and resonant frequency of the RFQ were close to the expected values following shipment of the RFQ from CRL, the verification of the modeling codes mandated that the field distribution in the structure be confirmed. The insertion of a probe through the vacuum pumping holes in each of the quadrants gave a perturbation measurement of the cavity fields from which the dipole field contributions to the quadrupole field were calculated. The uncorrected dipole fields across quadrants 1 and 3 (dipole 1) were measured up to 14% of the quadrupole field and up to 8% across quadrants 2 and 4 (dipole 2). The dipole field distribution along the RFQ

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length indicated that the vane coupling rings near the ends held the distribution close to the desired quadrupole configuration, thus, dipole field reduction at the center should achieve an acceptable field pattern in the RFQ. Adjustment of movable tuners in quadrants 2 and 4 and modification of the fixed tuner in quadrant 3 corrected the field distribution to less than 4% dipole contribution. This was considered acceptable for the beam studies. Figure 2 displays the corrected and uncorrected dipole contributions for dipole 1, the larger of the two dipole field distributions.

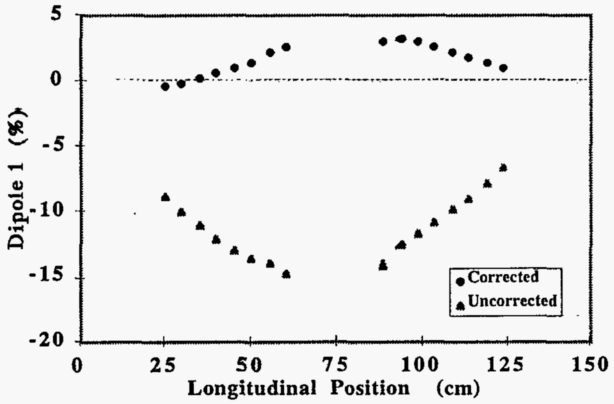

Figure 2. Dipole 1 contribution to the quadrupole field distribution.

A subsequent intervane gap measurement verified that the vanes had shifted away from their initial 1 mil tolerance and these gap differences were in agreement with the uncorrected dipole distributions.

3 HIGH-POWER FIELD LEVEL VERIFICATION

The calibration of the field sampling loops were completed using a Hewlett Packard 8753 Network Analyzer, and the rf signals from these loops at high power were monitored using power meters and oscilloscope measurements of the raw rf signals and diode rectified signals. The RFQ was conditioned to high power based on the SUPERFISH prediction of the design power level. High-power measurements of the actual field level were made using the x-ray endpoint method [4], a technique pioneered by accelerator scientists at CRL. Measurements made throughout the duration of the proton beam studies verified that the peak intervane gap voltage tracked the measured power levels according to the expected square root dependency. Figure 3 displays the gap voltage data and the curve used to project the peak intervane gap voltage as a function of measured power.

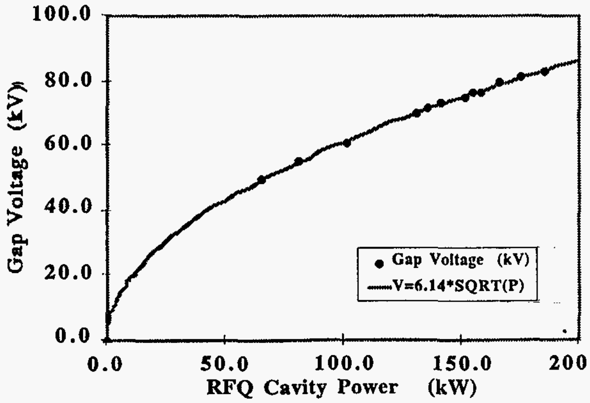

Figure 3. Peak intervane gap voltage versus RFQ cavity power.

4 SPARK RATE ANALYSIS

During the CRITS RFQ operation, the spark rate has been systematically measured and stored. Every second, the total number of sparks was read on a counter. Every minute, the raw number of sparks was stored as well as the number of seconds with at least one spark. In fact, this last information was found to be more relevant, since avalanches of sparks do not bias it. The rf power levels (forward, reflected and in cavity) were also recorded, as well as the residual vacuum pressure (Figure 4). We established that the spark rate has some influences on vacuum, but there is no evidence of any reciprocal effect.

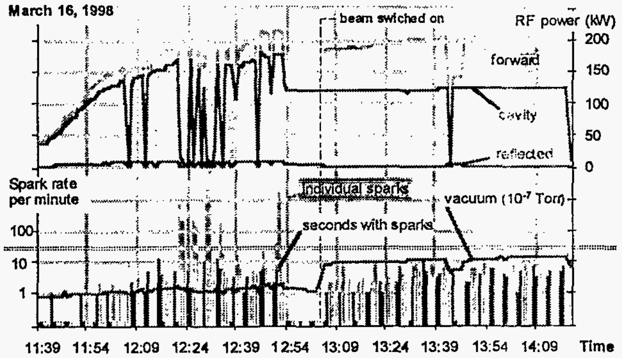

Figure 4. Example archived rf power operating data.

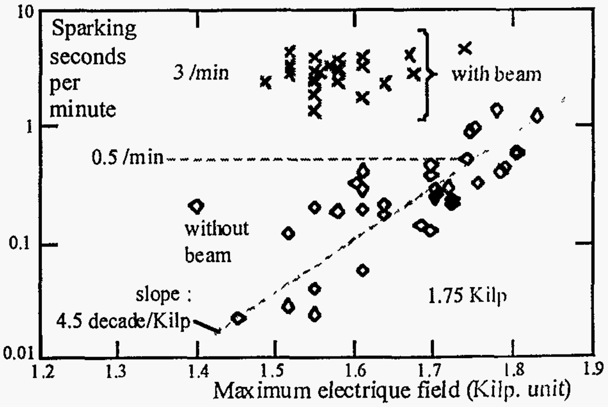

Figure 5. Average spark rates during long runs.

Within the stored data, a set of long runs (between 22 and 163 minutes long) of continuous operation have been extracted: 34 runs without beam and 24 with beam. For each run, the average rate of sparking seconds was computed. As some runs yielded no sparks at all, one spark has been added arbitrarily to each data point in order to be able to plot the zero-spark points on a log scale (figure 5). This induces a slight bias to the data, but takes into account the fact that rates are more accurate if acquired over a long run.

Without beam, the rate is typically 0.5 per min at the design field (1.75 Kilpatrick, 77.4 kV intervane voltage, 159 kW measured in the RFQ), i.e. the average time between two bunches of sparks is two minutes. The slope shows that a 0.22 Kilpatrick decrement in the electric field lowers the sparking tendency by an order of magnitude.

During beam operations, the RFQ was run about 10% below the design field because of a peak rf power limitation. The rate jumped to 3.0 per minute, depending neither on the beam current (20 to 80 mA) nor on the field (1.5 to 1.7 Kilpatrick tested). This is about 6 times more than without beam at 1.75 Kilpatrick.

With rates such as the ones measured here, one could not hope to build an RFQ that would be free of sparks over several months of continuous operation. For LEDA proton beam operations, it will probably be necessary to deal with a spark rate which requires that the LINAC restart automatically after a short power interruption.

5 PROTON BEAM MEASUREMENTS

The proton beam studies with the RFQ proceeded cautiously by increasing current only as the injector match to the RFQ could be confirmed by the beam transmission. The desired field level for the RFQ was set from the x-ray endpoint measurement, but a measurement of beam transmission as a function of the RFQ cavity power was also used to confirm the expected behavior. As expected, a knee in the transmission curve was observed below the design field level.

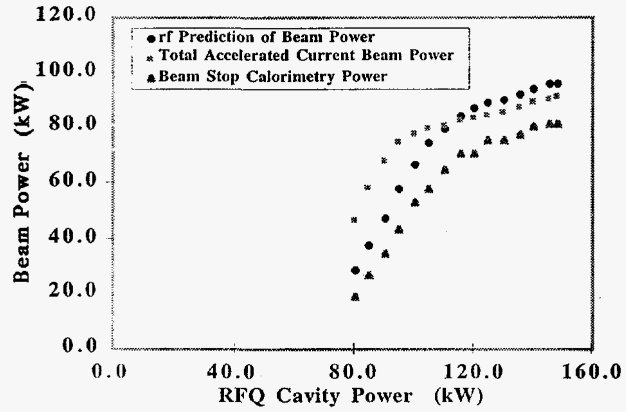

Figure 6. Beam power measurements from rf incident power difference, beam stop calorimetry, and predicted power assuming fully accelerated transmitted beam versus RFQ cavity power.

As a separate check for accelerated beam, the incident power difference and beam stop calorimetry were compared to the expected beam power under the assumption that the entire proton beam was accelerated. This assumption is known to be false but allows us to compare the beam transmission data with the two beam power measurements using the same units. These data are shown in Figure 6. The rf incident power difference and calorimetry measurements of the beam as a function of RFQ cavity power shows a discrepancy in absolute calibrations, but the knee in the curve for both measurements agree. The lower RFQ cavity power correlated with the knee for beam transmission compared with the other power measurements indicates that beam is transmitted even though it is not accelerated.

6 SUMMARY

The CRITS RFQ proved to be the best test device for checking out all components of the injector. By optimizing the current through the RFQ, all injector systems demonstrated that they could operate across the required parameter space. The procedures developed in preparing the RFQ for beam and in accomplishing beam studies should expedite successful operations with the LEDA RFQ. The successful transmission of beam currents with good agreement to the simulations [5] also provides confidence in the codes as we proceed into future projects.

7 ACKNOWLEDGMENTS

We would like to thank and express our appreciation to the personnel at Chalk River Laboratories who designed, fabricated, assembled, and commissioned this accelerator section under the RFQ1 program. They provided an RFQ which met its design goals and proved to be robust enough to operate reliably through a long sequence of structure studies. Furthermore, their brilliant and innovative work provided not only the basis for the x-ray endpoint measurement which has proven so valuable at LANL, but also the underlying technical knowledge for cw, proton accelerator development which has been the cornerstone of the upcoming LEDA project.

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