Operational Characteristics of a 100-mA, 2-MeV Radio-Frequency Quadrupole*

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Abstract

A 100-mA, 2.07-MeV Radio-Frequency Quadrupole (RFQ III) has been commissioned and operated routinely on the Accelerator Test Stand (ATS) [1] at Los Alamos National Laboratory. To characterize the RFQ output beam dynamics, measurements were made of the beam transmission and of the transverse and longitudinal phase-space distributions. Data were taken for different RFQ III operating conditions and compared to simulations.

I. INTRODUCTION

The ATS experimental program had the objective of comparing measured performance of an accelerating structure to predicted performance. The evaluation was made by comparing measured and predicted beam transmission, position and angle centroids, energy and phase centroids, and transverse and longitudinal phase-space distributions. RFQ III was the third RFQ in a series of RFQs [2,3] to be tested on the ATS. Pertinent RFQ III design parameters: frequency is 425 MHz, number of cells is 358, length is 289.23 cm, design vane potential is 111 kV, average radius is 0.4047 cm, final radius is 0.278 cm, final modulation is 1.83, initial synchronous phase is -90°, final synchronous phase is -30°, peak surface field is 32.7 MV/m, nominal current limit is 167 mA, and design acceptance at 100 mA is 0.232 π cm-mradian. This paper presents the RFQ III commissioning results.

II. EXPERIMENTAL TECHNIQUE

The H^- input beam to the RFQ was obtained from the ATS, 100-keV source and accelerating column [4]. A low-energy, beam-transport section (LEBT) followed the column. The LEBT consisted of four permanent magnet quadrupoles (PMQs) and two electromagnet horizontal and vertical steerers. The PMQs could be moved along the beam axis. Moving the PMQs varied the input match to the RFQ. The RFQ was operated at a low duty factor (0.025%).

The experimental objective was to fully characterize the output beam of the RFQ to allow for a detailed comparison to the simulation codes. To achieve this end, the output-beam current, beam transmission, and transverse and longitudinal phase-space distributions were measured for a variety of RFQ operating conditions.

Diagnostics for these measurements included broad-band toroids (current and transmission), a LEBT Faraday cup (current), an electric-sweep emittance scanner in the LEBT [5], two pairs of slit-collectors (transverse emittance), Laser Induced Neutralization Diagnostic Approach (LINDA) [6] (longitudinal emittance), a momentum spectrometer (momentum centroid and spread), and an x-ray detector [7] (RFQ rf field).

III. EXPERIMENTAL RESULTS

The RFQ vane potential is the only adjustable variable of the RFQ. It affects the transverse and longitudinal focusing of the beam. The RFQ vane potential was determined from end point measurements of the x-ray energy spectrum generated by electrons accelerated across the vane gap [7]. The x-ray energy spectra were measured versus cavity rf power and used to calibrate rf pickup loops in the RFQ. The pickup loops were used to set the RFQ vane potential. The RFQ operating voltage range was 95 to 138 kV.

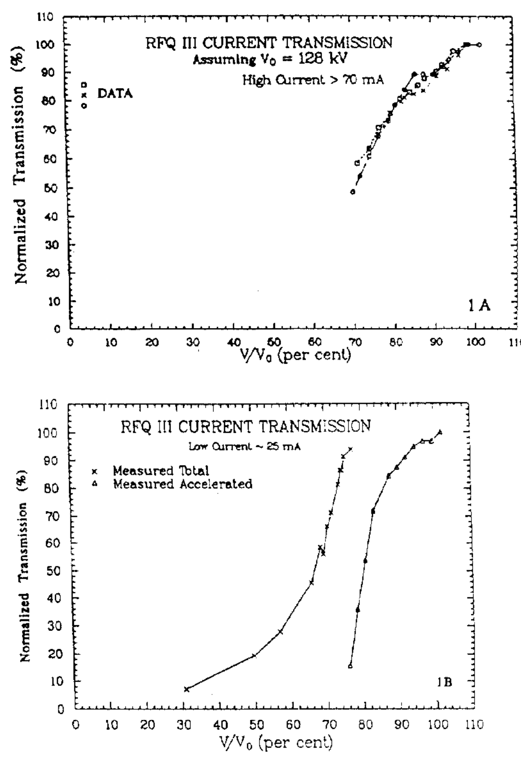

Figure 1. Normalized beam transmission versus normalized vane potential V for high- and low-beam currents.

The RFQ III beam transmission was measured versus the vane potential for various input beam currents. Figure 1A shows the total beam transmission for beam currents >70 mA. Figure 1B shows the total and accelerated beam transmissions for currents ~25 mA. At high currents, the plots have the same shape, regardless of input beam conditions. Although not shown, simulations show the same vane potential

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dependence as the data. The magnitude of the measured high current transmission never exceeded ~85%, whereas simulations predict ~90% transmission. Typically the measured transmission was 65% to 70% due to a beam mismatch at the RFQ entrance. The transmission knee occurs at a vane potential of 128 kV rather than the design value of 111 kV.

The beam momentum was measured with a focusing spectrometer that consisted of two quadrupoles, primarily for vertical containment, and a horizontal 60° bending magnet with circular pole tips [3]. At the design vane potential the beam had the predicted energy of 2.07 MeV.

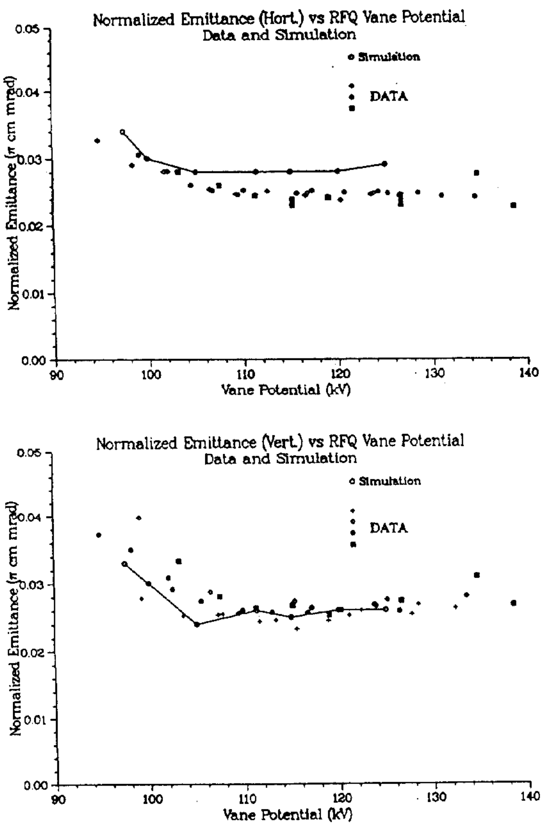

Figure 2. Measured and simulated transverse emittances versus normalized vane potential V for 78% of the beam. V_0 equals 128 kV. Horizontal and vertical data are shown.

The output RFQ transverse phase-space distribution was measured versus vane potential. The phase-space distributions (horizontal and vertical) were measured with a standard slit and collector technique [8]. The rms normalized emittances were measured for the vertical and horizontal planes. The RFQ input beam was matched in all cases. Figure 2 shows data and simulations. The data sets correspond to measurements made on different days. The scatter in the data gives the typical day-to-day reproducibility of the beam. The measurement error was 5 to 8% with background subtraction being the dominant component. The agreement between data and simulations was better in the vertical plane than in the horizontal. In both planes, the emittance flattens off at ~110 kV which is consistent with the design value of 111 kV but inconsistent with beam transmission results.

The measured Courant-Snyder (CS) parameters were compared to simulations. The data are shown in Fig. 3. The data sets correspond to measurements from different days. There was qualitative agreement between data and simulations as the vane potential was varied. For RFQ II the agreement was good [1]. The discrepancy for RFQ III probably is due to differences between the as-built and as-designed RFQ, which have not been incorporated into the simulations. A determination of these discrepancies will require off-line checks of RFQ III at a future date.

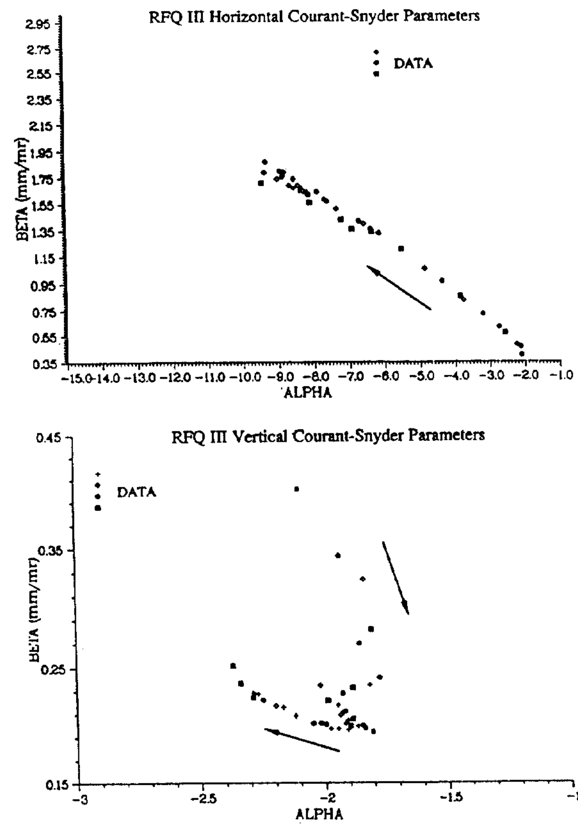

Figure 3. Horizontal and vertical CS parameters versus RFQ III vane potential for 78% of the beam. The arrows indicate the direction of increasing vane potential.

Figure 4 shows the vertical phase-space distributions for data and simulations. The parallelogram shapes at lower vane potentials are due to off-energy particles.

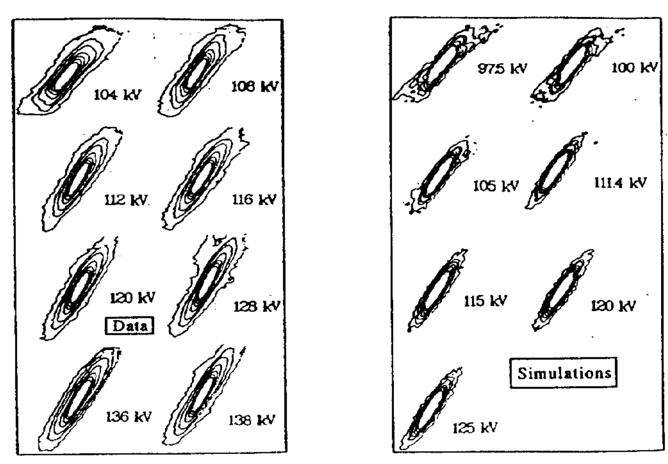

Figure 4. The vertical phase-space distributions for data and simulations for different vane potentials.

The RFQ output transverse phase-space distribution was measured versus the match of the input beam. For large variations in the input mismatch factor [9] (i.e., in the shape of the input beam), the output CS parameters and emittance remained nearly constant; agreeing with simulations. The beam transmission varied with the input match resulting in decreased beam brightness for large mismatches.

Longitudinal phase-space distributions were measured using the LINDA technique [6]. The measured and simulated distributions appear similar (Fig. 5), but the measured emittance is ~60% of the simulated emittance (Fig. 6). The difference is many times the uncertainty in the data which is estimated to be ~5%. This difference between the data and simulations is not understood, but a likely explanation is the difference between the as-built and as-designed RFQ. For the GTA RFQ, there was good agreement with data and simulations [10] giving confidence in the measurement technique and simulations codes. For power levels ≤120 kV the longitudinal phase-space distributions begin to change from elliptical to crescent-shaped (Fig. 5). The change is caused by off-energy particles. These data indicate that RFQ III should be operated at 128 kV rather than the design value of 111 kV.

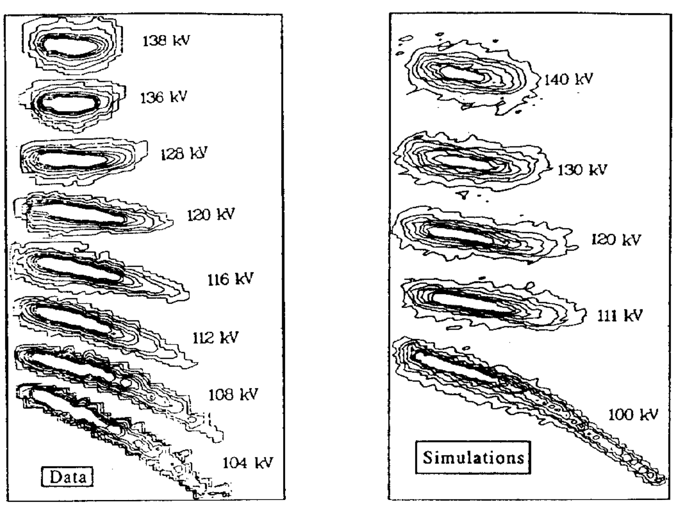

Figure 5. Measured and simulated longitudinal phase-space distributions versus vane potential.

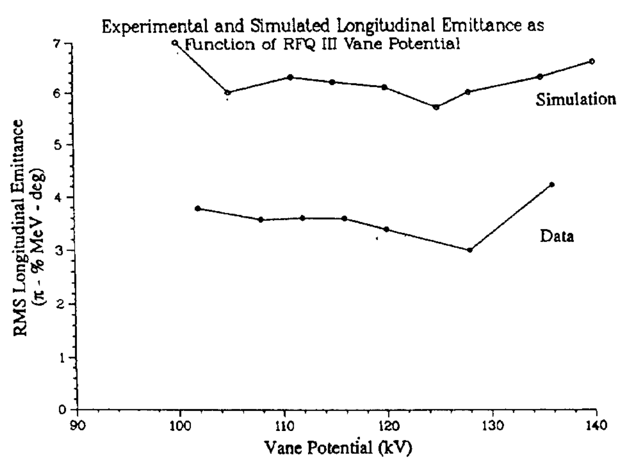

Figure 6. The rms longitudinal emittance for data and simulation versus vane potential.

IV. SUMMARY AND CONCLUSIONS

RFQ III was successfully commissioned and operated routinely and reliably. The RFQ performance was largely as expected. The longitudinal-emittance discrepancy between data and simulations is not understood but appears to be real.

IV. ACKNOWLEDGMENTS

The commissioning of the ATS RFQ would not have been possible without R. D. Patton and the ATS rf team; S. D. Orbesen and the ATS injector personnel; M. L. Milder and the ATS facility support team; and the LINDA personnel.

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