COMMISSIONING OF THE GROUND TEST ACCELERATOR RFQ*

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Abstract

The Ground Test Accelerator (GTA) has the objective of verifying much of the technology (physics and engineering) required for producing high-brightness, high-current H^- beams. GTA commissioning [1] is staged to verify the beam dynamics design of each major accelerator component as it is brought on line. The commissioning stages are the 35-keV H^- injector, the 2.5-MeV radio-frequency quadrupole (RFQ), the intertank matching section (IMS), the 3.2-MeV first 2-$\beta\lambda$ drift tube linac (DTL-1) module, the 8.7-MeV 2-$\beta\lambda$ DTL (modules 1-5), and the 24-MeV GTA (all 10 DTL modules). Commissioning results from the RFQ beam experiments will be presented along with comparisons to simulations.

Introduction

This paper addresses the commissioning of the GTA RFQ, which was designed to accelerate a beam of 55 mA from 35 keV to 2.5 MeV with high transmission and high brightness. To characterize the RFQ output beam performance, experiments were made with low-current (~18 mA) and high-current input beams. Variations in RFQ output beam parameters such as transverse and longitudinal emittance, Courant-Snyder (CS) parameters, transverse and longitudinal centroids, and transmission were studied as functions of the input beam parameters (e.g., energy, match, and transverse centroids), RFQ rf power (RFQ vane voltage), and time in the macropulse.

RFQ Experiments and Results

Commissioning of the RFQ was completed in June 1991, although experiments have continued after beamline installation of the intertank matching section (IMS) [2]. The RFQ conditions rapidly and operates reliably with few cavity breakdowns. Its input beam is provided by the GTA injector, which was designed to match a 35-keV, 55-mA H^- beam to the RFQ. The injector consists of a H^- source and a low-energy beam transport (LEBT) beamline. Pertinent GTA injector RFQ parameters are given in Reference 1.

Transverse emittances at the LEBT midpoint emittance station (ES1) and RFQ match point (ES2) have been significantly reduced over time with LEBT upgrades. Before the latest GTA operation, rms normalized emittances in both transverse planes at ES1 and ES2 were, respectively, ~1.7 and ~2 times design. During the most recent commissioning experiments, ES1 emittances were relatively stable and were in the range of ~1.33 to ~1.67 times design.

The principal GTA diagnostics [3-4] available for RFQ commissioning were located on a diagnostics plate (D-plate) and included (1) two sets of slits and collectors for measuring horizontal and vertical (i.e., x and y) transverse phase space and position and angle centroids (designated x or y and x' or y', respectively); (2) a toroid for measuring beam current; (3) three microstrip probes for measuring x, y, energy, and phase centroids; (4) a capacitive probe for measuring phase spread; and (5) laser-induced neutralization diagnostic approach [5-6] (LINDA) for measuring longitudinal phase space and energy and phase widths. The D-plate was designed for commissioning of the RFQ, IMS, and DTL-1. An additional two toroids are located in the entrance and exit end walls of the RFQ.

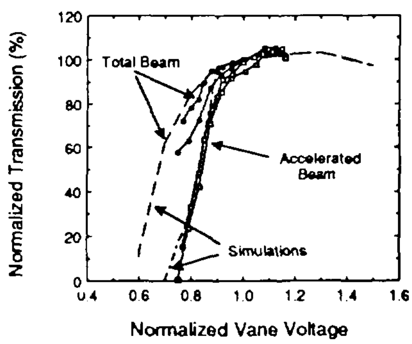

Fig. 1 Normalized beam transmission versus the RFQ normalized vane voltage.

Output beam parameters were compared with results of simulations to evaluate RFQ performance. Measurements of transmission versus vane voltage were consistent with simulations (Fig. 1), although high-current, large-emittance beams did not achieve the design maximum transmission. The knee in the transmission curve occurred at 62 kW of cavity power (gap voltage was ~56 kV, corresponding to a normalized vane voltage of 1 in Fig. 1). The 35-keV design injection energy gave the maximum beam transmission of 82 ±2% for low currents (input and output currents were 27 and 22 mA, respectively) and of 72 ±2% for high currents (input and output currents were 45 and 32 mA, respectively). This transmission is consistent with simulations when effects of larger-than-design input emittance, image charges, and RFQ multipoles are included. RFQ transmission exhibited broad maximums for variations in LEBT steering and movement of the RFQ entrance. The effects of LEBT match on beam

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transmission were clearly visible, with best transmission near the design RFQ CS parameters.

Figures 2 and 3 show the RFQ input and output currents and transmission plotted against time in the macropulse. Although beam transmission varies in time, the RFQ output transverse emittances and CS parameters do not [2].

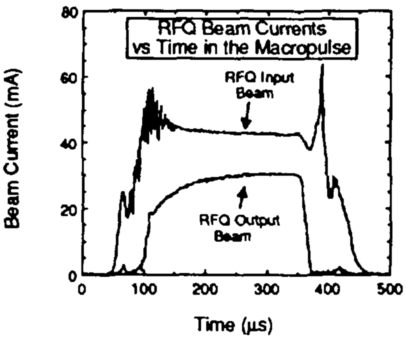

Fig. 2. RFQ input/output beam current versus time.

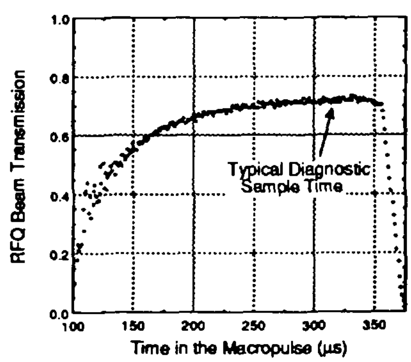

Fig. 3. RFQ beam transmission versus time.

The RFQ output-beam transverse phase space was measured as a function of the RFQ cavity power or, equivalently, the vane voltage. The relative rms normalized emittance dependence on vane voltage is shown in Fig. 4. At design vane voltage, measurements and simulations agree if simulations are based on "as measured" RFQ input emittances rather than design values. For input and output currents of 27 mA and 22 mA, the rms normalized transverse emittances were a factor of ~1.9 and ~1.5 times design for x and y , respectively. The CS α and β parameter dependences on vane voltage were as expected. At design vane voltage, the mismatch factor [7-8] MM between the measurements and simulations are in reasonable agreement with MM <0.4 for x and MM <0.2 for y (Fig. 5). At low cavity power (45 to 40 kW), the RFQ transverse phase-space distributions change from their characteristic elliptical shapes to ones more similar to parallelograms (Fig. 6). The data are supported by simulations that indicate that the change is due to off-energy particles.

RFQ output beam centroid changes were approximately equal to input centroid changes for either RFQ entrance movement or LEBT steering in x. LEBT steering in y produced inconsistent results in the output x and y centroids. RFQ output emittances were constant within measurement error over the range of LEBT match variations.

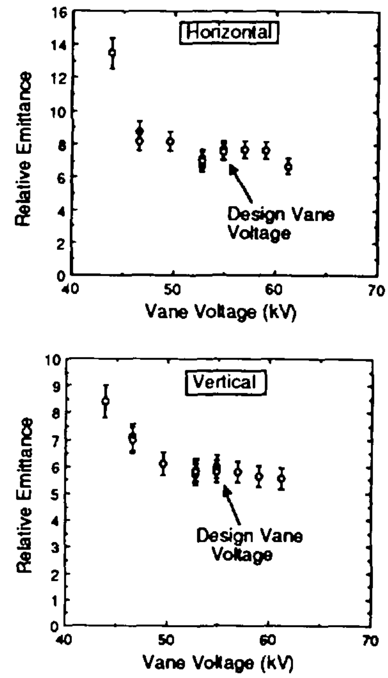

Fig. 4. Relative normalized rms transverse emittance versus the RFQ vane voltage.

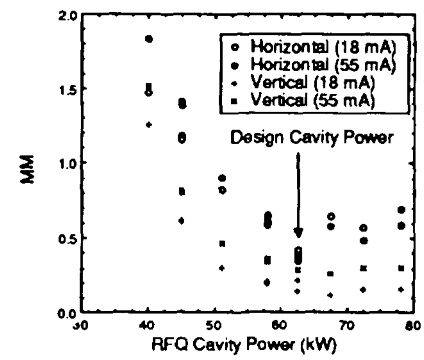

Fig. 5. Comparison between data and simulations for horizontal and vertical MM versus RFQ cavity power. Simulations are based on output currents of 18 and 55 mA while data were obtained for an output current of 22 mA.

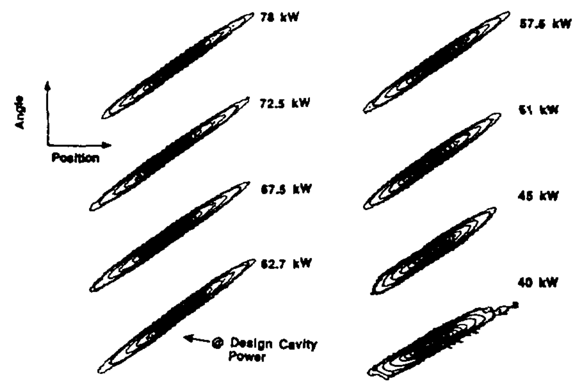

Fig. 6. RFQ vertical transverse phase space distributions as a function of RFQ cavity power.

The RFQ output beam longitudinal phase space was measured as a function of the RFQ vane voltage, the RFQ injection energy, and the LEBT match. Data and simulations showing the dependence of the relative longitudinal rms emittance and CS β parameter on vane voltage are presented in Figs. 7 and 8. For cavity powers ≥62 kW, there is good agreement between measurement and simulations (MM <0.1 at design cavity power). For cavity powers <62 kW, the agreement is poor for reasons which are not yet understood. For power levels <52 kW, the longitudinal phase-space distributions begin to change from circular to crescent-shaped (Fig. 9). The change is caused by off-energy particles. The LINDA and capacitive probe measurements of beam phase spread were in relatively good agreement.

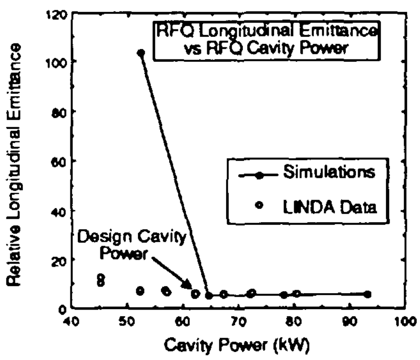

Fig. 7. Relative longitudinal rms emittance vs cavity power.

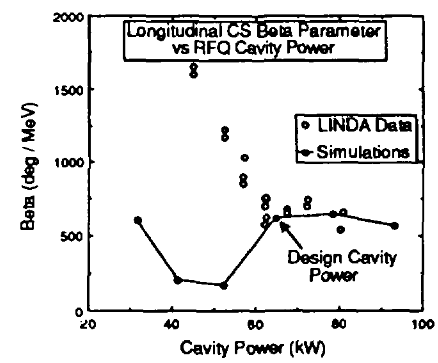

Fig. 8. The longitudinal CS β parameter vs RFQ power.

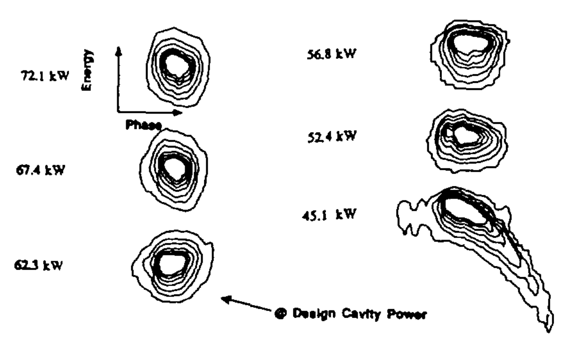

Fig. 9. RFQ longitudinal phase space distributions as a function of RFQ cavity power.

As the RFQ injection energy was varied from 33.5 to 36 keV in 0.5-keV steps, the longitudinal phase space was observed to vary little. The minimum phase space occurred at the design injection energy of 35 keV. Over a limited range of LEBT matches, the measured longitudinal phase space did not exhibit significant variations.

Summary

Commissioning of the GTA RFQ has been completed. The RFQ has been shown to be reliable. The RFQ performance is as expected on the basis of comparisons with simulations that utilized the as-measured input beam.

Acknowledgements

The successful completion of the RFQ commissioning would not have been possible without the cooperation of many individuals throughout the Accelerator Technology division of LANL. In particular, GTA operation would not have been accomplished without the excellent assistance of the AT-10 injector section; AT-5 for rf support; M. L. Milder and the GTA facility support team; AT-8 for software support; the AT-3 diagnostics section; R. Garcia and M. Shinas for LINDA support; M. Smith in the experimental support and data acquisition and analysis effort; and E.V. Hawkins, L.B. Dauelsberg, and C. Vigil for the alignment of the beamline.

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