

## Commissioning of the First Drift Tube Linac Module in the Ground Test Accelerator\*

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### Abstract

The Ground Test Accelerator (GTA) [1] has the objective of verifying much of the technology required for producing high-brightness, high-current H<sup>-</sup> beams. GTA commissioning is staged to verify the beam-dynamics design of each major accelerator component as it is brought online. The major components are the 35-keV H<sup>-</sup> injector, the 2.5-MeV radio-frequency quadrupole (RFQ) [2], the intertank matching section (IMS) [3], the 3.2 MeV first 2 $\beta\lambda$  [4] drift tube linac (DTL-1) module, and the 24-MeV GTA with 10 DTL modules. Results from the DTL-1 beam experiments will be presented.

### I. INTRODUCTION

This paper addresses the commissioning of the GTA DTL-1 module which was successfully completed in March 1993. The DTL-1 was designed to control emittance growth and to maintain high beam transmission and brightness. DTL-1 is the first of five 2 $\beta\lambda$  DTLs. The second five DTLs are 1 $\beta\lambda$  structures. The DTL was divided into 10 modules for ease of fabrication and drift-tube alignment. More details on the DTL and GTA are given in References [1], [2], and [3].

To evaluate the DTL-1's performance with beam, the commissioning plan encompassed numerous experiments. The DTL-1 position acceptance was measured both by displacing the beam and moving DTL-1. The DTL-1's output transverse and longitudinal phase-space distributions were measured versus the IMS permanent variable field quadrupole (VFQ) strengths, the IMS buncher rf amplitudes and phases, time in the macropulse, and the DTL rf amplitude and phase set points. The rf set points of the DTL-1 cavity were determined with beam by comparing measurements of the beam's energy and phase centroids with predictions. The x-ray energy spectrum from the cavity was measured versus cavity rf power. These data provide an independent verification of the rf amplitude set point [5]. Data were taken to obtain the effect of IMS steering and DTL-1 position on the DTL-1 output beam position centroids. These data can be used to determine an equivalent R transfer matrix for DTL-1. Jitter measurements were made of the beam current, position, energy, and phase [6]. RF studies were completed to assess the rf control system performance [7].

### II. DTL EXPERIMENTS AND RESULTS

There were two principal GTA diagnostic [8] systems available for the DTL-1 commissioning. The first system was installed on a moveable plate (D-plate) and consisted of (1) two sets of slits and collectors for measuring horizontal and vertical transverse phase space, and position and angle centroids; (2) a toroid for measuring beam current; (3) three microstrip probes for measuring position, energy, and phase centroids; (4) a capacitive probe for measuring phase spread; and (5) Laser Induced Neutralization Diagnostic Approach (LINDA) [9] for measuring longitudinal phase space, and energy and phase widths. The D-plate was designed to commission, individually, the RFQ, IMS, and DTL-1.

The second system consisted of beamline diagnostics permanently installed on GTA. Two toroids, located in the entrance and exit endwalls of the RFQ, monitor beam transmission. Within the IMS beamline, there were (1) three microstrip probes; (2) a toroid; and (3) a video profile monitor (VPM) [10] for measuring transverse beam profiles and position centroids at the IMS exit.

Like the RFQ and IMS bunchers, the DTL-1 cavity conditioned rapidly to high power and operated reliably with few cavity breakdowns.

As expected, beam losses in the DTL-1 were small. Beam transmission was >98% (output current 35 mA). This high transmission was typical for most configurations of the IMS VFQs, buncher cavities, and permanent magnet quadrupole (PMQ) steerer settings. Significant transmission decreases occurred only for abnormal accelerator configurations, where beam losses were limited by the GTA Fast Protect system. The DTL-1 position acceptance for high transmission was  $\pm 1$  mm horizontally or vertically from the DTL center.

The microstrip probes are used in determining the rf set-points of DTL-1 using the phase-scan technique [11,12]. This technique uses the probes to measure beam energy and phase centroids versus the DTL-1 rf amplitude and relative phase. Single-particle simulations provide the shape signature for determining the rf amplitude set point. Figures 1A and 1B show simulation results and experiment data, respectively. The plotted points for each rf field correspond to a different input cavity phase. For a given cavity field, the input phase set point occurs at the zero normalized energy (Fig. 1A). The  $\sim 15$  keV offset from zero in the data (Fig. 1B) is due to uncertainties with the absolute energy measurement calibration. Simulations and data exhibit the same counterclockwise rotation as the cavity power increases. Figure 2 shows the gap-voltage dependence of the slope of the

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phase scan linear region. There is good agreement between data and simulations.

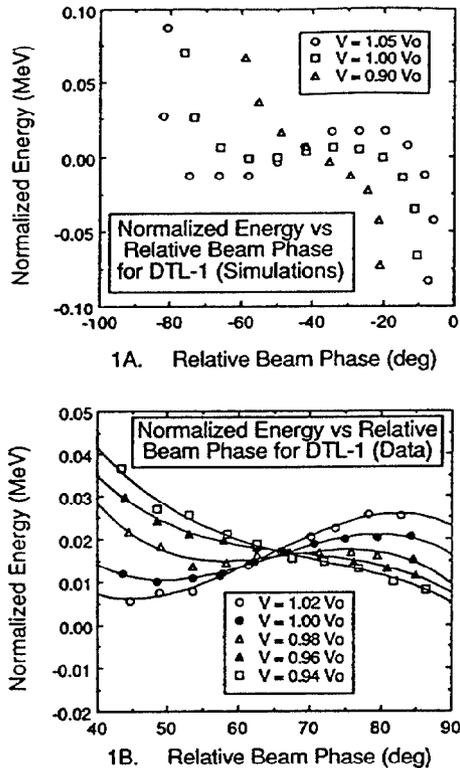


Figure 1. Normalized beam energy (design minus actual energy) versus the relative beam phase for DTL-1.  $V_0$  is the design gap voltage. Relative phase is used to ease curve shape comparison.

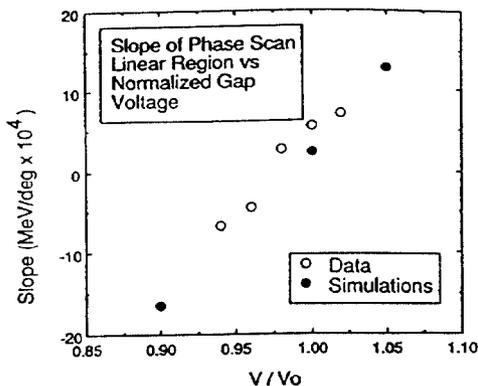


Figure 2. Slope of phase-scan linear region versus the normalized gap voltage  $V/V_0$ .

We assume that the DTL rf cavity power  $P$  (kW) is related to the DTL gap voltage  $V$  (kV) through a relationship of the form  $V = K\sqrt{P}$ , where  $K$  is a proportionality constant determined by either experiment or theory. SUPERFISH calculations, using the measured  $Q$  of the DTL-1 cavity, give  $K = 18.04$ . From x-ray and phase-scan measurements,  $K = 17.97$  and  $K = 18.22$ , respectively. The agreement between data and theory is  $\sim 1\%$ . Experimental and theoretical uncertainties are  $\sim 3-5\%$ .

The RFQ beam transmission varies during the macropulse [2], but the RFQ and IMS transverse phase-space distributions and the IMS transmission do not [3]. Measurements show that the DTL-1 beam transmission and output transverse phase-space distributions, including position centroids, do not change during the macropulse. The insensitivity of the mismatch factor  $MM$  [13] (i.e., the Courant-Snyder (CS) parameters or beam shape) to time is shown in Fig. 3.

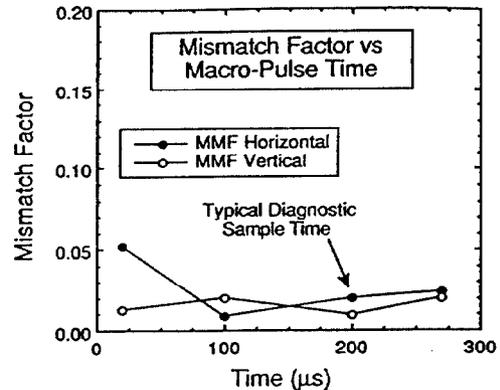


Figure 3. Horizontal and vertical  $MM$  versus time within the macropulse.

The DTL-1 output transverse phase-space distributions were measured as a function of the IMS transverse tune. Except for abnormal conditions (e.g., an IMS buncher off), the output CS parameters were insensitive to the tune. Their measured values were found to be near the ideal, design output values (Fig. 4) where a practical criteria of  $MM < 0.3$  is considered good. Each run number in Fig. 4 corresponds to a particular IMS tune. Values of  $MM \geq 0.4$  occurred for abnormal IMS configurations. The DTL-1 output emittances were independent of the DTL input and output CS parameters. No transverse/longitudinal coupling was observed for different IMS longitudinal tunes.

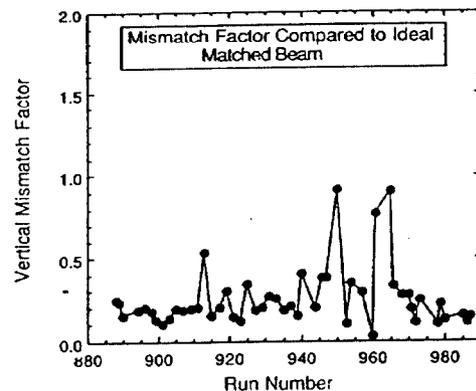


Figure 4. Vertical  $MM$  (DTL-1 output beam) between measurements and ideal beam.

The longitudinal DTL output phase-space distribution was measured versus IMS longitudinal tunes. As in the transverse case, the longitudinal emittance and CS parameters were insensitive to variations about the standard IMS tune. The CS parameters varied little from their ideal, design output values. Large deviations in the output emittance and CS parameters could be achieved for extreme IMS longitudinal tunes (e.g.,

operating the downstream IMS buncher in its debunch, acceleration, or deceleration modes).

The transverse and longitudinal phase-space distributions were measured as functions of the DTL-1 rf power and phase set points. The power and phase were varied from the optimum values by  $\pm 10\%$  and  $\pm 20$  degrees, respectively. The longitudinal and transverse distributions were largely insensitive to DTL-1's amplitude and phase. For the transverse distributions  $MM < 0.3$  for all set points.

A comparison of the DTL-1 output transverse and longitudinal emittances to those obtained out of the IMS during its commissioning indicates that there is little or no emittance growth through the DTL-1, as expected.

The DTL-1 output-beam-position centroids depend on the input centroids which were varied with IMS steering or DTL-1 entrance displacements. The data verified our IMS steering model. Analysis is underway to use these data to obtain an equivalent R transfer matrix for the DTL. The trace of the determined R matrix equals two times the cosine of the phase advance. The results will be compared to theory.

One PMQ steerer is attached to the exit of each DTL module for adjusting the position centroids at the next DTL module. Exercising the DTL-1 steerer resulted in expected changes in beam centroids.

For transverse phase-space measurements, a comparison was made between the standard slit and collector technique, which measures the full  $H^-$  beam, and the transverse LINDA [14] technique, which uses the same slit and collector to measure a photoneutralized portion of the  $H^-$  beam. The neutralization point is upstream ( $\sim 32$  cm) of the emittance gear slit. The two methods yield different results. The difference is real and is predicted by simulations that include the different space-charge effects between the neutralization point and the slit. Three experiments were made with different degrees of bunching. The more bunched the beam, the greater the difference between the techniques (Fig. 5). The two experimental techniques agree with predictions.

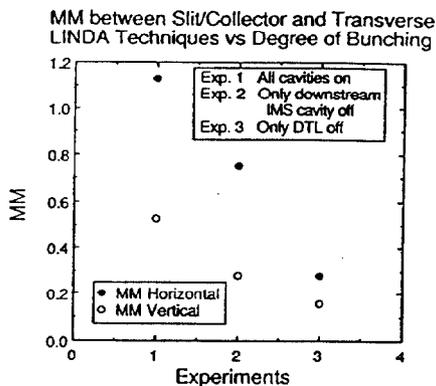


Figure 5. MM (between the two techniques) vs degree of bunching.

### III. SUMMARY

DTL-1 is commissioned and fully operational. The injector, RFQ, IMS, and DTL-1 operations were reliable and stable, allowing for extensive beam measurements. High beam transmission was obtained with little or no transverse- and longitudinal-emittance growth through DTL-1. The

measured CS parameters are in good agreement with simulations as are the phase-scan data.

### IV. ACKNOWLEDGEMENTS

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