*PHASE-SCAN ANALYSIS RESULTS FOR THE FIRST DRIFT TUBE LINAC MODULE IN THE GROUND TEST ACCELERATOR: DATA REPRODUCIBILITY AND COMPARISON TO SIMULATIONS**

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The Ground Test Accelerator (GTA) had the objective of producing a high-brightness, high-current H^- beam. The major accelerator components were a 35 keV injector, a Radio Frequency Quadrupole, an intertank matching section, and a drift tube linac (DTL), consisting of 10 modules. This paper discusses the phase-scan technique which was used to experimentally determine the rf operating parameters for the commissioning and routine operation of the first DTL module.

I. INTRODUCTION

The objective of phase-scans is to experimentally find, with beam, the rf operating parameters for an accelerator cavity (e.g. drift tube linac (DTL) modules or buncher cavities). The operating parameters to be determined are the relative rf cavity (or input beam) phase and the rf gap voltage (or cavity power) in the cavity. The rf phase and gap voltage can be obtained from measurements of the output beam longitudinal centroids (i.e. energy and phase) and their comparison to theoretical expectations (i.e. simulations)[1,2,3]. Because phase-scan measurements are intended to be made routinely in the turn on of an accelerator (e.g. GTA), it was important to establish the reproducibility of such measurements. The experimental results and comparisons to simulations are presented here.

II. MEASUREMENT

The phase-scan technique was utilized in the two commissioning beam periods of the first GTA DTL module (DTL-1). A microstrip beam probe system was used to measure the beam's longitudinal centroids [4,5] as a function of the DTL-1 gap voltage and cavity phase. The output beam phase was acquired by measuring the signal phase difference between a rf cavity-field probe signal and the signal from a microstrip probe downstream of the cavity. The beam energy was obtained by measuring the phase difference between the signals of two microstrip probes located downstream of the cavity and separated by a know distance. The phase difference was converted to a time-of-flight (TOF) from which the beam energy was calculated. A comparison of the measured beam phase and energy dependence on the gap voltage and cavity phase to the expected theoretical dependence provides the signature for the determining the cavity's operating set points.

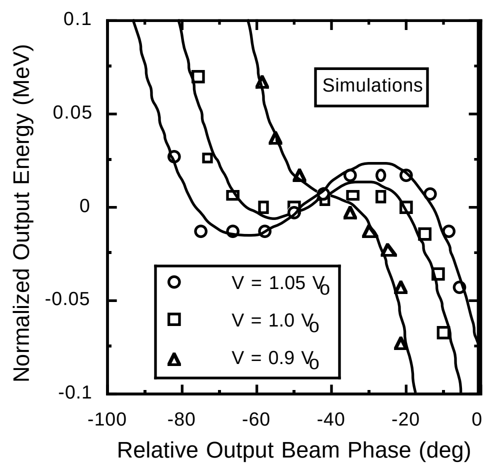

Figure 1: Single-particle simulations of the normalized output beam energy as a function of the relative output beam phase for three DTL-1 gap voltages (V_0 is the design gap voltage). The curves are meant to guide the eye.

II. SIMULATIONS

Single-particle simulations using PARMILA provide the shape signature for determining the gap voltage (cavity power) set point. In this procedure, it is assumed that beam centroids are unaffected by space-charge and that the longitudinal centroid behavior can be predicted by single-particle simulations. Both assumptions are reasonable if the particles in the bunch experience forces that depend on the magnitude of their displacement from the synchronous particle. Figure 1 shows such single-particle simulations for three rf fields corresponding to 1.05, 1.00, and 0.90 times the design gap voltage V_0. The vertical axis is the normalized output beam energy (actual minus the design energy) and the horizontal axis is the relative input beam phase. 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. As the cavity field increases the simulations exhibit a

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counterclockwise rotation. All simulations assume the DTL-1 design input energy of 2.50 MeV.

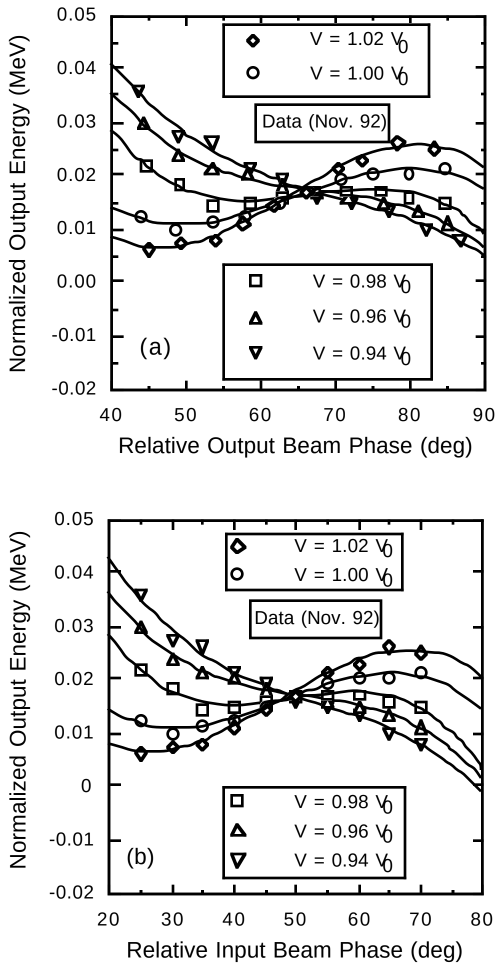

Figure 2: Measured normalized output beam energy as a function of the (a) output and (b) input beam phase. Data are from Nov. 1992 and were obtained for five DTL gap voltages (V_0 is the design gap voltage). The curves are meant to guide the eye.

IV. EXPERIMENTAL RESULTS

Figure 2 shows the measured phase-scan data from the Nov. 1992 commissioning beam period. The data were obtained using an automated phase-scan code which, for a fixed cavity field, systematically varied the rf input phase in uniform steps of 5 degrees, starting from an initial phase of -120 degrees. Scans were made for five rf amplitudes corresponding to gap voltages that were 0.94, 0.96, 0.98, 1.00, and 1.02 times V_0. Figure 2a (2b) shows the normalized output energy dependence on the relative output (input) beam phase. The solid curves are meant to guide the eye. The data and simulations show the same counterclockwise rotation as the DTL gap voltage increases.

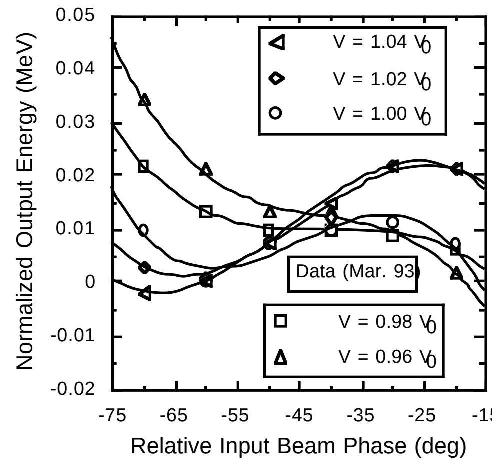

Figure 3: Measured normalized output beam energy as a function of the relative input beam phase. Data are from Mar. 1993 and were obtained for five DTL-1 gap voltages (V_0 is the design gap voltage). The curves are meant to guide the eye.

The measured phase-scan data from the Mar. 1993 commissioning beam period are shown in Figure 3. Because the automated phase scan code was unavailable, phase-scans were made manually (i.e. the rf input phase was varied manually and the output energy was recorded). In this mode the output phase was not determined. To reduce measurement time, the input phase was varied in 10 deg steps rather than the 5 deg used in Nov. 1992. These data show the counterclockwise rotation for decreasing DTL gap voltage as did the simulations and earlier data.

To compare the Nov. 1992 and Mar. 1993 data sets to each other and to simulations, the slopes of the central linear portions of the phase-scans were determined. This was done using the input or output beam phase as the independent variable in the phase-scans plots. The slopes were used to specify the orientation of each scan in the output energy and phase plane. By comparing the change in slopes with respect to changes in gap voltage, the phase-scan counterclockwise rotation was quantified and comparisons were made between data sets and simulations.

The choice of points to be included in the linear region is somewhat arbitrary. In this case the choice was guided by considerations of the Mar. 1993 data and to the sensitivity of the slopes on the input phase range $\Delta\phi_{in}$ or output phase range $\Delta\phi_{out}$. This led [6] to an interval of $\Delta\phi_{in}$ = 30 deg or $\Delta\phi_{out} \approx 25$ deg being chosen. Since the output beam phase was not determined for the Mar. 1993 beam period, a full comparison of all data and simulations was only possible for phase-scans using the input beam phase as the independent variable (see Figs. 2b and 3). The results are shown in Fig. 4 where the consistency between data and the agreement to simulations is good. A similar comparison between the Nov. 1992 data and simulations using phase-scans with $\Delta\phi_{out} \approx 25$ deg was equally good.

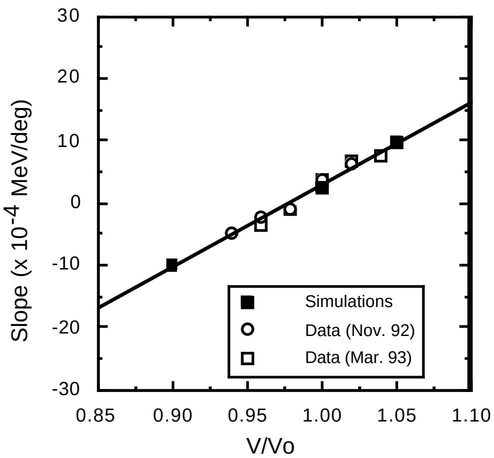

Figure 4: Comparison of the slopes of the linear regions of the DTL-1 phase-scans for all data and simulations. A consistent comparison of data sets resulted in a choice of $\Delta\phi_{in} = 30$ deg. The line is a linear fit to the simulations.

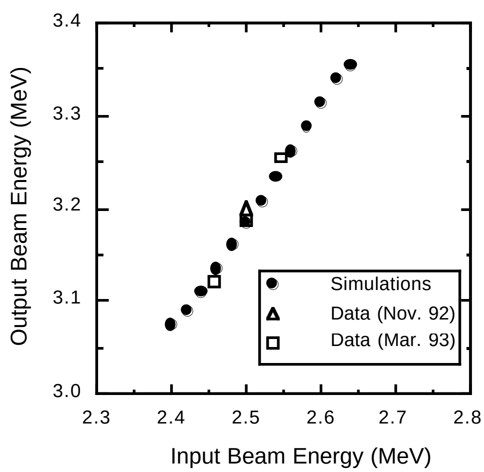

Figure 5: The DTL-1 output beam energy as a function of the input beam energy (data and simulations). There was only one point from the Nov. 92 data set because the input energy was not varied. The DTL was set at its design field (i.e. $V/V_0 = 1$).

In the above discussion, the DTL-1 input energy was fixed at its design value of 2.50 MeV. In the Mar. 1993 beam period a complementary set of measurements were made where the input beam phase was held fixed (at its experimentally determined set point of ≈ -45 deg) and the input energy was varied. This was accomplished by changing the phase of a downstream buncher cavity in the Intertank Matching Section (IMS) [7]. Only limited energy variations were allowed by this technique (i.e. 2.50 ± 0.046 MeV). The dependence of the measured DTL output energy on input energy and a comparison to simulations is given in Figure 5. The agreement between measurement and expectations is good.

Determination of the of the operating DTL gap voltage was obtained by a comparison of the measured shapes in Figs. 2 and 3 to the expected shapes in Fig. 1. With this criteria the experimental $V/V_0 = 1$ setting agreed with simulations to within 1%. This was independently verified by measuring the energy spectrum of the x-rays generated within the DTL cavity in the absence of beam [8,9].

V. SUMMARY

The phase-scan measurements from the two DTL-1 commissioning beam periods were very reproducible. This was independent of the mode in which the phase-scans were made (automated or manual). The data were in good agreement with single-particle simulations.

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