H^- Beam Characterization using Laser-induced Neutralization*

V. W. Yuan, R. Garcia, K. F. Johnson, K. Saadatmand,†
O. R. Sander, D. Sandoval, M. Shinas
Los Alamos National Laboratory, Los Alamos, NM 87545

Abstract

The Laser-induced neutralization technique, LINDA, is important as a noninterceptive diagnostic for quantitatively measuring beam emittance values. It is also valuable for its capability to characterize, both quantitatively and qualitatively, the performance and match of linac components. In this paper we present LINDA experimental results that show how the output beam of a radio-frequency quadrupole (RFQ) and drift-tube linac (DTL) combination changes with the variation of RFQ-DTL relative phase and of DTL cavity power. We also present results showing the effect of a longitudinal buncher on beam emittance.

1 Introduction

The Laser-induced neutralization technique, LINDA, was developed primarily to quantitatively measure emittances of a high-intensity H^- beam. Because of its noninterceptive nature, the technique can be used continuously in a high-intensity beam without the survival problems that would accompany the use of an interceptive diagnostic. When used on the Los Alamos 5-MeV Accelerator Test Stand (ATS), LINDA has also proved to be an important diagnostic in characterizing the performance and match of various components of an accelerator structure. As an example, LINDA allowed the ATS experimental team to measure the longitudinal emittance at the exit of individual structures and provided information about the shape of the beam longitudinal phase space as a function of the operational settings of the accelerator elements. Because quantitative emittance values are discussed in another paper at this conference [1], this paper concentrates on how LINDA can be used to verify the optimum DTL field setting, the correct buncher setting, and finally, the optimum relative phase setting between the RFQ and the DTL.

*Work supported and funded by the US Department of Defense, Army Strategic Defense Command, under the auspices of the US Department of Energy.

†Grumman Corporate Research Center.

0-7803-0135-8/91$01.00 ©IEEE

2 Experimental Setup

A schematic of the LINDA setup for the ATS measurements is given in Yuan et al. [1]. The 1.064-μm fundamental from a pulsed, mode-locked YAG laser was amplified and frequency-doubled to produce intense pulses of 532 nm wavelength. The mode locking, in conjunction with pulse slicing, produced short, 5-Hz single pulses of 23 ps duration and 20-30 mJ average intensity. The laser beam intersected the ATS H^- beam at a location 6.3 cm downstream of the end of the DTL. The setup was basically the same one used in experiments to determine emittance growth and therefore a second laser intersection point was present 17.7 cm downstream of the end of the DTL. The neutralized portion of the beam was separated from the charged remainder with a bending magnet, and neutrals were detected with a secondary emission monitor (SEM) located 9.5 meters downstream of the laser intersection points. The time-of-flight (TOF) spectra of the arriving neutrals were digitized with a Tektronix AD7912 waveform digitizer, and the laser firing times were determined by a Nanofast 536-10B time-interval meter. TOF spectra and Nanofast times were recorded for analysis using a MicroVax II computer.

3 Characterization Results

Optimal transmission of the particle beam through both the RFQ and DTL sections of the accelerator depends on matching the settings of the two sections to the proper values. As the settings depart from the optimal values, transmission can suffer causing beam intensity to drop. However, with LINDA, we were able for the first time to see the actual change in shape of the longitudinal-emittance phase space that accompanies the reduction in transmission. Figure 1 shows a map of the observed longitudinal phase space as a function of the relative RFQ-DTL phase and of DTL cavity power. For each phase and amplitude setting at which a measurement was taken, one observes a pair of phase-space contours (reflecting the presence of the two laser intersection points, as mentioned above). The similarity of the two contours in each pair indicates that no major changes in emittance shape occur in the 11.4-cm

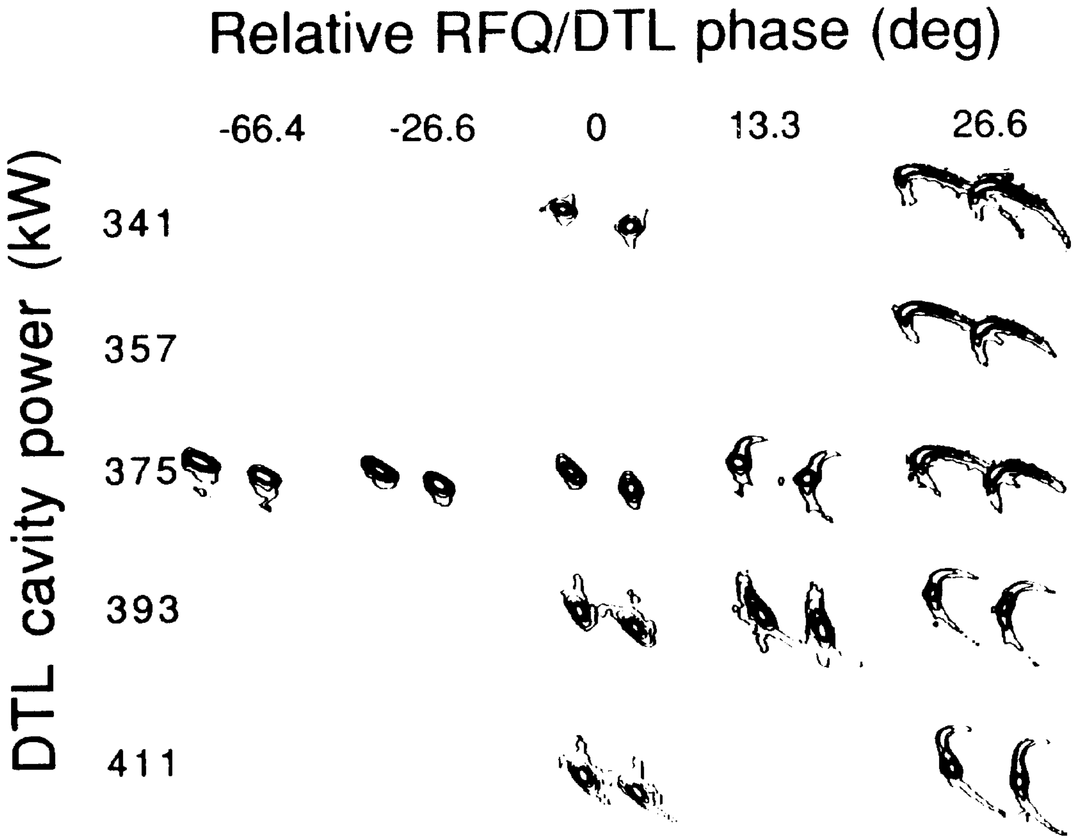

Figure 1: Map of longitudinal-emittance phase space plots measured for various DTL cavity power levels and for various RFQ/DTL relative phases.

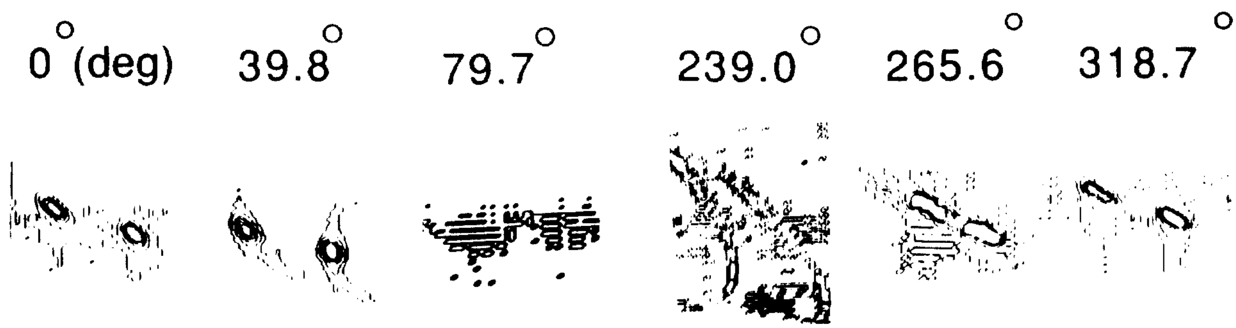

Figure 2: Succession of emittance plots depicting the change in longitudinal emittance as the relative RFQ/DTL phase undergoes a full 360 degree wraparound.

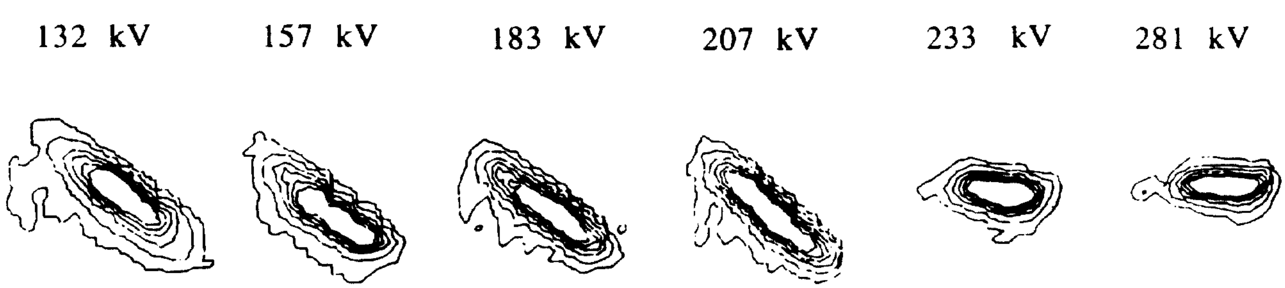

Figure 3: Plots of longitudinal emittance for different gap voltages of the "R1" buncher.

drift space between the laser intersection points.

Optimal transmission occurred at the relative phase setting of -26.6° and a DTL power of 375 kW. One can see that the phase space remained elliptical for changes in relative phase of approximately 30° to 40° from this setting. At relative phase settings of 13.3° and 26.6°, the mismatch between RFQ and DTL resulted in the growth of long tails in the emittance phase space. The appearance of these tails is evidence that beam particles are beginning to fall out of the rf beam bucket. Figure 1 shows that with the relative phase held constant at 26.6°, a variation in the DTL power resulted in a marked rotation of the orientation of the long phase-space tails. In repeating the measurements, we found that the phase setting for the onset of the rotations could change. This was later traced to a problem with the potentiometer on the trombone of the phase shifter. Hence, in addition to its value in determining emittance, LINDA allowed the experimental team to discover and correct an uncertainty in determining the overall relative phase.

A further variation of the relative RFQ-DTL phase can result in a large mismatch in which the entire beam falls out of the rf bucket and the transmission falls to zero. Figure 2 shows the longitudinal phase-space plots as the relative RFQ-DTL phase is wrapped around a full 360°. One sees the progressive distortion of the phase-space ellipse, followed by the eventual disappearance of the beam. The beam reappears when the wraparound nears 360°.

4 Buncher Modes

In a later stage of ATS development, a beam transport line [2] consisting of one arm of a beam funnel was installed immediately downstream of the DTL. After the first buncher of this funnel arm was installed, LINDA was used to characterize the buncher output beam. When a beam micropulse passes through the buncher, the phase of the power cycle that the buncher is in (buncher mode) determines the effect that the buncher will have on beam emittance. A micropulse passing through the buncher while the buncher field is changing most rapidly, will either be bunched or debunched, depending on whether the field is increasing or decreasing with time. In addition, since the average energies at the front of the bunch are altered relative to those at the rear of the bunch, the phase ellipse will be rotated after the beam has passed through the buncher. The bunch and debunch modes have the largest effect on beam phase space. If the beam enters the buncher field 90 degrees out of phase with the bunch or debunch modes, then the bunch is either accelerated or retarded (deaccelerated) as a whole without much change to the shape of the emittance ellipse. Figure 3 shows the effect of the buncher as a function of buncher gap voltage. One sees that there is no visible effect of the buncher until the gap voltage exceeds 200 kV. In Figure 4, the output emittance for each of four buncher modes is shown. For comparison,

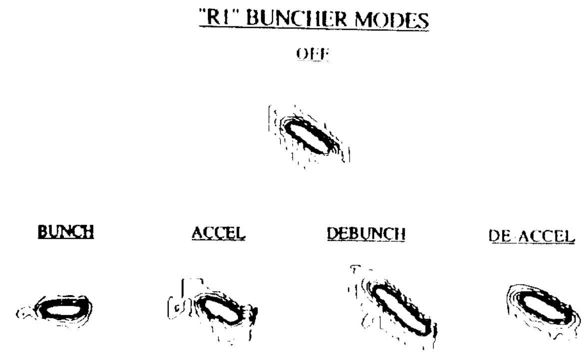

Figure 4: Measured longitudinal emittance for four different "R1" buncher settings and for buncher off.

the emittance is also shown for buncher off.

5 Summary

The capabilities of LINDA as a diagnostic go beyond its primary function of quantitatively determining emittance sizes. LINDA can also serve as a valuable check on whether set points for rf fields, buncher settings, and RFQ/DTL relative phases are optimal. When these set points are varied far enough from their optimal settings to affect the transmission of the beam, LINDA permits experimenters to graphically see the changes in longitudinal phase space that are causing the losses in transmission.

References

[1] V. W. Yuan, R. Garcia, K. F. Johnson, K. Saadatmand, O. R. Sander, D. Sandoval, and M. Shinas, *Measurement of Longitudinal Emittance Growth Using a Laser-induced Neutralization Method*, 1991 Particle Accelerator Conference, San Francisco, CA, May 1991.

[2] K. F. Johnson, O. R. Sander, G. O. Bolme, J. D. Gilpatrick, F. W. Guy, J. H. Marquardt, K. Saadatmand, D. Sandoval, and V. Yuan, "A Beam Funneling Demonstration: Experiment and Simulation," in *Proceedings of the International Symposium on Heavy ion Inertial Fusion*, Monterey, CA, Dec. 1990.