MEASUREMENTS OF THE LONGITUDINAL BEAM PARAMETERS IN THE FERMILAB LINAC

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Abstract

The Fermilab Linac Upgrade has increased the energy of the H^- linac from 201 to 401.5 MeV. This is achieved by replacing the last four 201.24 MHz drift-tube linac cavities with seven 804.96 MHz side-coupled cavity modules. Each accelerator module is powered with a 12 MW klystron-based power supply. The purpose of this report is to present a body of representative methods and data used to characterize longitudinal properties of the beam after each accelerating tank and module. These various methods proved useful in the commissioning of the Fermilab Linac Upgrade.

Phase-Scan

The Phase-Scan Match algorithm[1] is a relatively simple method for tuning the Alvarez and Side Coupled linacs. Tank/Module phase is varied over 360 degrees while the phase of signals from strip-line detectors is measured. The reference phase is taken from the master oscillator for the linac. Theoretical curves of beam phase versus tank/module phase are matched to the measured curves to determine the tank/module field amplitude and phase. Figure 1 is a typical example of the phase-scan procedure. For this module (Module 1), the algorithm determines that electric field is 4% larger than the design value. Our simulations results suggest that the phase-scan signature matching technique may provide accuracies of a few tenths of a percent if tank/module and beam phases can be determined to ±1 degree. It is our expereance that random phase measurement errors can be kept around one degree. This accuracy is adequate for the Fermilab linac and most other linacs, as well. We have used Time-of-Flight measurements and the classical Delta-T technique as additional checks in the process of longitudinal tuning.

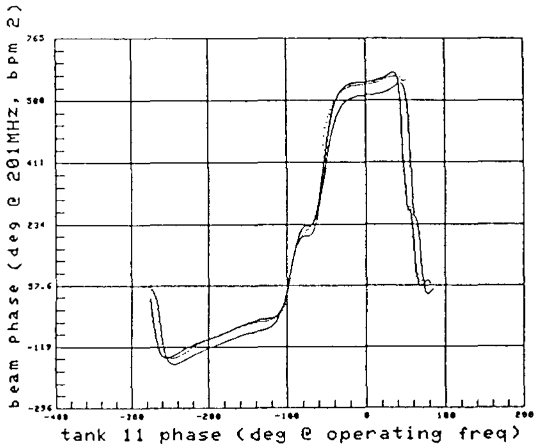

Figure 1. Upper curve is fit to data points. Lower curve is the target curve for Module 1.

Time-of-Flight

Time-of-flight was also used to measure the velocity of the beam[2]. This provided a very simple way to check other techniques as one only needs distance and time. We used two BPM's in the new linac, one in the transition section and another near the end of the first module. Survey data provided the distance while a high frequency scope and a network analyzer provided the time information. The signals from the two BPM's were displayed on a 2GHz scope. The cable lengths leading to each were varied until the signals were superimposed. The cable lengths were then mea-

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sured using the network analyzer. To make it easier to superimpose the two signals, the pulse structure of the beam was modified so that the entire pulse was approximately 50 nsec long. In this way the entire pulse could be displayed by the scope (see Figure 2.) at a resolution comparable to that of the network analyzer.

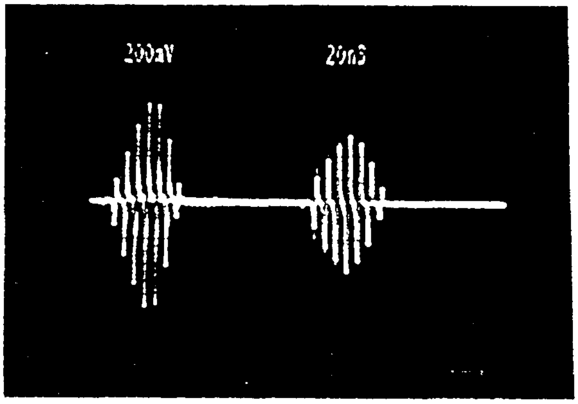

Figure 2. This is a photo of the scope screen. The larger amplitude signal is the seven bunch signal at first detector, while the second trace is the same bunch train at the downstream detector.

While the linac normally operates with a 35 microsecond string of 200 MHz micropulses, the low energy beam transport line was modified to produce approximately 10 micropulses. Normally the LEBT uses electrostatic chopper plates to remove the beginning and end of the DC beam produced by the source. Here, the chopper circuit was modified to sweep the beam across the LEBT transverse aperture. The aperture of the beamline then truncates the beam to a strip approximately 50 nanoseconds long which is captured by the buncher into the 10 micropulses. Surveys indicated that the two BPM's were separated by 6.829374 meters. The difference in the cable lengths was 49.91 nsec. This gives a beta of .4564 or E= 116.36 Mev. The design of the linac specified that the output beta of the drift tube linac should be .4569 which is within .1% of our measurement. Our estimated errors for the measurements were .12 mm in length and .1 nsec in time for a combined error of .2%.

The Fermilab linac is an injector to the Booster synchrotron, so the energy of the beam has to be constant to a level of $\frac{\Delta T}{T} \leq 2.0 \times 10^{-3}$ pulse to pulse. The stability of the Linac beam energy is monitored using the phase of the beam-induced rf signal at a stripline detector 30 meters downstream of the linac. Phase detection of the beam signal is performed using an I&Q demodulator. As reference signal we are using the linac rf reference line.

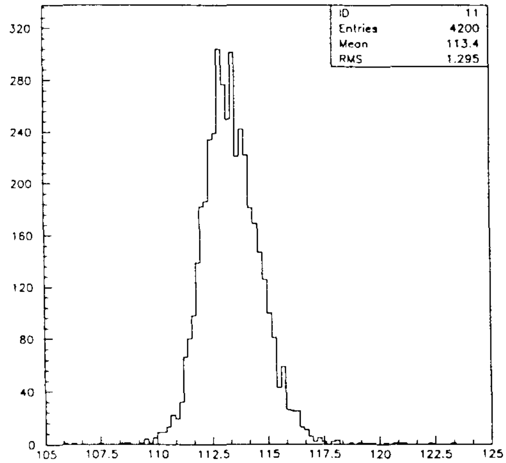

Figure 3, $\frac{\Delta T}{T} = 3.414 \times 10^{-4} \times$ # **degrees at 201MHz, horizontal axis is in 201MHz degrees.**

Figure 3. shows that out of more than 4000 linac pulses, maximal variation of the beam phase is ±3.5 degree, which translates to $\frac{\Delta T}{T} = 0.1\%$. Energy variations during individual linac pulses is monitored using a stripline detector (BPM) after a 40 degree bend. The spectrometer magnet which produces this 40 degree bend is regulated better than $\frac{\Delta B}{B} = 3.0 \times 10^{-4} \times$ using an NMR probe (see Figure 4).

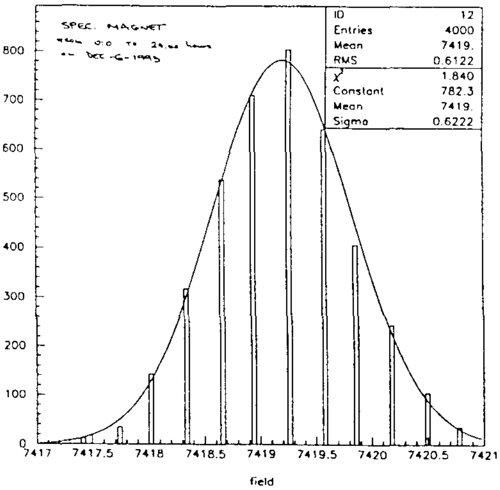

Figure 4. Regulation of spectrometer magnetic field.

The signal from the BPM is digitized using 2MHz quick digitizer and displayed using linac control system. Figure 5 shows the position of the linac beam during a 20μsec micropulse. Arrows indicates the portion 10μsec of the beam which is tranferred the Booster. Variation of the position of the beam translates to an energy variation of $\frac{\Delta T}{T} = 0.1\%$.

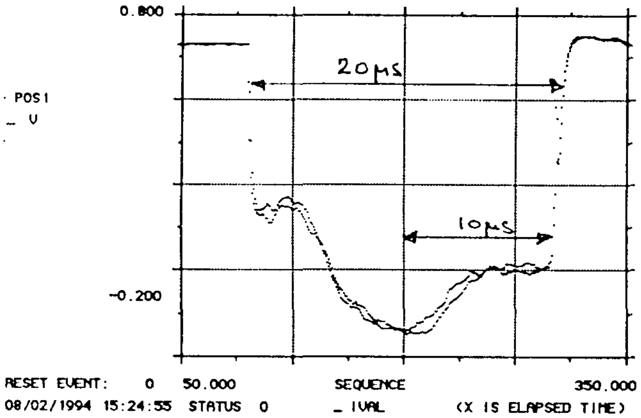

Figure 5. Beam position variation within a 20μsec macropulse.

Delta-T Measurments

The classical Delta-T technique[3] was occasionally used to check the longitudinal tuning performed by the Phase-Scan Match algorithm. The scanning range of the Delta-T procedure is typically only 10 degrees compared to the 360 degree scan of the Phase-Scan Match algorithm. Agreement between the two methods was somewhat mixed. Typically the Delta-T and Phase Scan measurements agreed upon the input energy of the beam to within measurement uncertainties, however in several instances the proper phase setting as determined by the Delta-T procedure was significantly higher (10 to 15 degrees) than that found by the Phase-Scan Match algorithm. Agreement between the two methods upon the rf amplitude was ±4%. These measurements indicated no gross errors between the methods, however further study is needed to determine the cause of the discrepancies.

Bunch Lenght Monitor

This device is described in detail in [4]. It measures the average bunch length of a train of particle bunches over the course of the 30 second measurement time. This is accomplished by synchronizing the deflection of a secondary electron beam, created from the ion beam passing through a wire at high voltage, to the RF which bunches the beam. Adjusting the phase of this deflection allows density of different longitudinal slices of the beam to be measured. The BLD in the 400 MeV area, 0.4 m downstream of Module 7, has been used to analyze the longitudinal emittance of the Linac beam.

References

[1] T. L. Owens, at al., "Phase-Scan Signature Matching for Linac Tuning," to be published in Particle Accelerators

[2] M. B. Popovic, at al., "Time-of-Flight Measurments of Absolute Beam Energy in the Fermilab Linac", Proceedings of 1993 Particle Accelerator Conference, pp. 1689-1691.

[3] K. R. Crandall, "The Delta-T Tuneup Procedure for the LAMPF 805 MHz Linac," LANL Report LA-6374-MS, June, 1976.

[4] E. McCrory, at al., "Use of an INR-style Bunch-Lenght Detector in Fermilab Linac", Proceedings of the 1992 Linac Conf., pp. 662-664.