OBSERVATIONS OF THE TRANSVERSE AND LONGITUDINAL NATURE OF THE FERMILAB LINAC BEAM

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Abstract: The installation of non-intercepting beam position monitors in the 200 MeV linac at Fermilab has facilitated several new observations on the character of the linac beam. We have discovered, in particular, two interesting phenomena: a high frequency ($\approx$ 3MHz) change in the beam position and a slow variation in the phase-lock loops during a 30μs beam pulse. We are also making progress in initiating the so-called "Δ–t" measurement[1].

Introduction

Beam position monitors (BPMs) have been installed in half of the 200 MeV H⁻ linac at Fermilab. These non-intercepting electrodes, depicted in Figure 1, have significantly improved the on-line diagnostics of this aging accelerator.

As one might expect, several measurements of the transverse beam properties have been made with the BPMs. A program for correcting beam vectoring has been initiated. We have also observed, and eliminated, a fast transverse oscillation in the beam position within the beam pulse, due to a two-stream instability in the 750 keV transport line when the vacuum in the line is poor (7×10^{-6} torr, gauge reading). Furthermore, we have observed and begun to correct a non-uniform betatron amplitude through the linac.

The longitudinal structure of the beam can also be measured with the BPMs. The RF signal directly from a detector strip can be viewed on an oscilloscope. Although the shape of the signal is dominated by the response of the detector and the attenuation of the signal cable, some information about the relative length of a bunch can be obtained. A different type of longitudinal information can be obtained by comparing the phase of the beam-induced signal with a reference signal, in this case the linac master oscillator. The drift of the beam within the RF bucket has been observed in this manner. Extending this method leads to the "Δ–t" measurement.

The detector consists of four plates in a quadrupole symmetry placed around the beam within the beam vacuum. RF signals from the passage of the charged beam within the aperture of the detector are detected, in varying degrees, by each of the four plates. Raw RF signals from opposite plates are used as input to an electronics module. This module converts a 200 MHz amplitude difference to a dc-level at the output with a bandwidth of 2 MHz[2]. The initial amplitude-to-phase conversion within the electronics module can be bypassed to change the module to a phase comparator. Further details of the mechanical and electronic design of these detectors have been presented elsewhere[3].

Transverse Measurements

Under the conditions described below, oscillations in the transverse position of the beam with amplitudes as large as 4 mm have

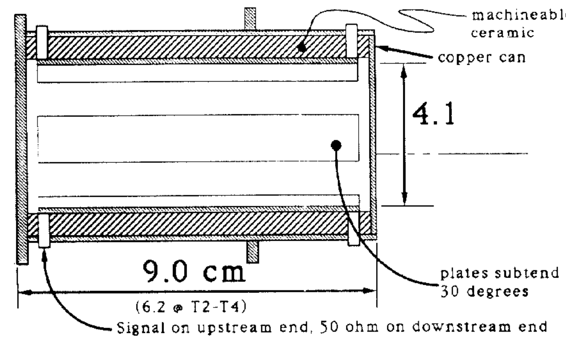

Figure 1: A typical Beam Position Monitor from the FNAL Linac.

been observed within the 30 μsec linac beam pulse. The oscillation takes about ten microseconds to develop. Identical oscillation, except for an overall amplitude factor, are observed simultaneously at each BPM.

These observations are made only while the pressure in the ten-meter 750 keV injection line is high. The effect is seen neither in the 4-meter injection line, high or low pressure, nor in the long line at low pressure (1.3×10^{-7} torr). Moreover, a four megahertz enhancement in the spectrum of the signal is seen[4] when the oscillations are large; no significant enhancements are seen otherwise. This is consistent with a two-stream instability formed in a H⁻ beam/positive hydrogen plasma system. The plasma frequency of this system is[5]:

$$\omega = \frac{4\pi n e^2}{m_p/2} \qquad (1)$$

where: n is the density of the H⁻ beam, $3 \times 10^8/cc$ for typical 58 milliampere beam at 750 keV, and $m_p/2$ represents the reduced mass of the H⁻ beam and the hydrogen gas background, m_p is the mass of the proton. This gives a plasma frequency of 3.6 MHz. The wavelength of this oscillation at 750 keV, $\beta = 0.04$, is four meters.

It has been observed[6] that a high pressure in the 750 keV line would reduce the effective emittance at injection into the drift-tube linac. The shape of the phase-space contour is improved, but at the price of large changes in the beam position during the beam pulse. We no longer run the line this way.

The Δ–t Procedure

The Δ–t procedure is a technique for adjusting the RF phase and amplitude in each of the accelerating modules of a linac. The technique has been developed at the Los Alamos National Laboratory where it is used routinely to tune the LAMPF accelerator modules[1]. We are planning to use the same procedure at Fermilab to tune accelerator modules in the linac upgrade[7]. We have initiated preliminary experiments on the existing linac to

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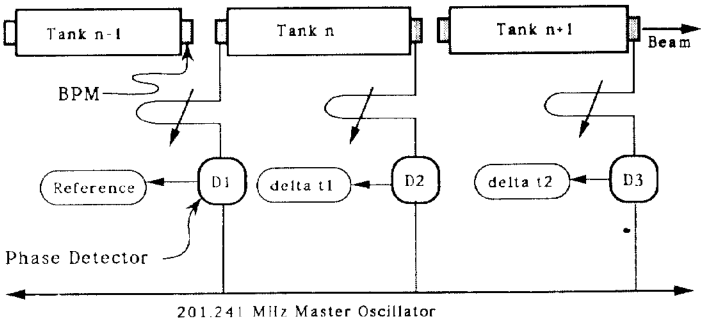

Figure 2: Schematic diagram of the Δ t measurement procedure.

study the technique. The procedure uses beam-induced signals from linac BPMs to determine changes in the times of flight of beam bunches when the tuned module is turned off and when it is turned on.

A schematic diagram is shown in Figure 2. All modules before the module being tuned are turned on, while all modules after the module being tuned are off. The changes in time of flight with and without RF in the module of interest are measured by determining the phase shift between BPMs, as show in the Figure.

Deviations in the changes in the times of flight from design values with RF versus without RF can be related to deviations in the module phase and input energy from design values according to:

$$\begin{pmatrix} \Delta t_B \\ \Delta t_A \end{pmatrix} = T \begin{pmatrix} \Delta \phi_A \\ \Delta W_A \end{pmatrix} \quad (2)$$

where Δt_B represents the deviations from design values for the change in time of flight between the beginning of the module being tuned and the end of the adjacent module; Δt_A represents the deviations from design values for the change in time of flight through the module being tuned; $\Delta\phi_A$ and ΔW_A are the deviations from design values of the module phase and input energy, respectively. The elements of the matrix T are related to elements of the transformation matrix for the module being tuned, as described in Reference [1]. This matrix depends in a calculable way upon the module RF field amplitude. It is expected, therefore, that variations in the Δ t's as the module phase is varied would depend upon the module electric field.

Preliminary experiments have been performed on the Fermilab linac which demonstrate this effect. Figure 3 is a typical example of the observations that have been made. Plotted in the figure is Δt_B versus Δt_A for tank 6 in our linac. Input energy is approximately 116 MeV. Each curve is generated by varying the phase in the module. Curves for four different electric field levels are shown. Distinct changes in slope as module phase is changed are apparent. Even more distinct is a turn-around of one of the curves in the figure. This turn-around occurs near the peak energy change in the module. Turn-around points are also observed for the other curves, but are not shown within the scale of this plot. The positions of these turn-around points in the Δ-t plane are extremely sensitive to the electric field. We are currently investigating this feature and the changes in the slope as a sensitive means of determining the module electric field level, as has been done at LAMPF.

Once the electric field level has been determined, the matrix T can be calculated. the module phase and input energy deviations from design can then be determined from Δ t information by multiplying both sides of Equation 2 by the inverse of the T matrix. Calculations of the inverted T matrix and of the phase dependance of energy changes out of the module are currently underway.

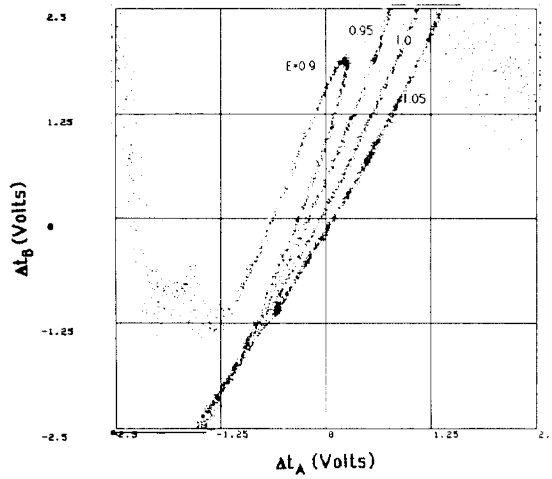

Figure 3: The variation in Δ t signals in tank 6 of the Fermilab linac as tank phase is varied for four different values of tank RF field level.

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References

[1] K. Crandall, "The Delta-t Tuneup Procedure for the LAMPF 805 MHz Linac," Los Alomos Scientific Laboratory Report LA-6374-MS (June, 1976).

[2] R. Webber *et al.*, "A Beam Position Monitoring System for the Fermilab Booster," Proceedings of the 1987 IEEE Particle Accelerator Conference, IEEE Catalog 87CH2387-9, pp 541-543.

[3] E. McCrory *et al.*, 1988 Linear Accelerator Conference, October 3-7, 1988 in Williamsburg, VA, proceedings are forthcoming.

[4] The higher bandwidth is obtained using an RF-detector and an RF amplifier. Amplitude insensitivity is poor in this arrangement.

[5] N. A. Krall and A. W. Trivelpiece, *Principles of Plasma Physics*, 1773, McGraw-Hill, p 9.

[6] C. D. Curtis, C. W. Owen and C. W. Schmidt. "Factors affecting H^- beam performance in the Fermilab Linac," 1986 Linear Accelerator Conference Proceedings, SLAC-report-303, September 1986, pp 138-140.

[7] Jim Maclachlan, "400 MeV Upgrade for the Fermilab Linac," paper M-7 of this conference.