Phase Scan Signature Matching for Linac Tuning

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Abstract

A conceptually simple method for tuning linac tanks has been tested on the Alvarez linac at Fermilab. Phases of beam-induced signals in stripline detectors are measured as tank phase is scanned over approximately 360 degrees. The stripline detectors are located downstream of the tank being tuned. The phase-scan curves have unique signatures that depend upon input beta and electric field. By matching theoretical curves of beam phase versus tank phase to measured curves, the important tuning parameters are determined. The tank parameters which are varied during curve matching include field amplitude, input beta, and relative tank-phase offset of the phase-scan curves. The actual phase of the tank fields relative to the design phase is found by noting the position of the actual tank phase along the phase-scan curve, once a curve match is obtained.

I. INTRODUCTION

The idea of comparing broad phase-scan signatures with theory to determine tank field amplitude, phase, and input beta was suggested at Fermilab a few years ago [1,2]. A similar idea was also proposed independently at the Los Alamos National Laboratory [3]. The early reports demonstrated that characteristic features of the phase-scan curves depend in unique ways upon input beta and tank electric field. References [4] and [5] are more recent papers which allude to the idea.

The phase-scan signature matching technique can be used to find all tuning parameters needed to center the beam in longitudinal phase space, including tank electric field, input beta, and tank phase. Originally, phase-scan signature matching was suggested as a means of coarse-tuning the Fermilab linac [1,2]. The classical delta-t procedure [6] was to be used for fine tuning.

One form of the delta-t procedure, which must be used on some of the linac tanks, assumes that the input energy equals the design value. This assumption can lead to errors in the procedure [2]. The phase scan signature matching technique, on the other hand, makes no assumptions about any of the tank parameters. In addition, the phase-scan signature technique can be used even if the tank settings are far from design values. The delta-t procedure assumes that the tank settings are close to design values. Our recent results as well as results published by LANL [3] suggest that the phase-scan signature matching technique may provide accuracies of a few tenths of a percent.

The phase-scan signature matching technique will be one of the tools used to tune the new Linac Upgrade at Fermilab [7]. Commissioning is scheduled to commence in late summer of this year. Although the phase-scan technique by itself appears sufficiently accurate to properly position the beam in longitudinal phase space, we presently plan to use the delta-t procedure, and spectrometer measurements to confirm phase-scan signature matching results.

II. EXPERIMENTAL PROCEDURES

The basic idea behind the phase-scan measurements is illustrated in figure 1. In the figure, tank N is the tank being tuned. All upstream tanks are turned on and all downstream tanks are turned off. The rf power for tank N is initially turned off. The phase of the beam induced signals (beam phase) at a downstream monitor is then recorded. This zero-power beam phase reading is subtracted from all subsequent beam phase readings. The theoretical beam phases are similarly referenced to a zero-power phase (unaccelerated beam).

Radio-frequency power to tank N is next turned on, and the beam phase is recorded as a function of tank N phase. The tank phase is varied over approximately 360 degrees. The tank phase signal is derived from direct measurements of tank fields using pickup loops in the tanks. Phase detection for both the beam signal and the tank signal is performed using I&Q demodulators. This technique was first suggested to us by workers at the Los Alamos National Laboratory [8].

The detector output is periodic, repeating every time the input phase changes by 2π. The beam phase can vary over a range much greater than 2π radians, necessitating measures to eliminate potential ambiguities in the

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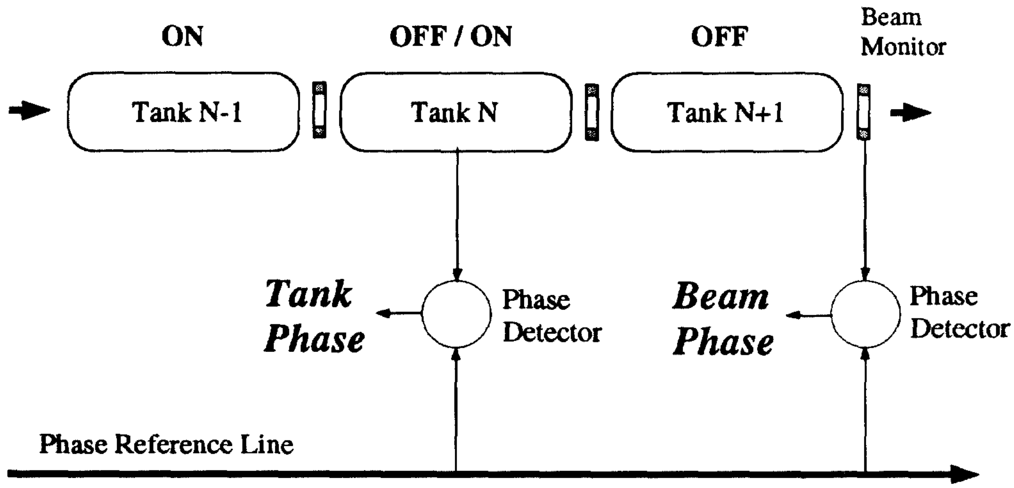

Figure 1. *Schematic diagram of the phase-scan signature monitoring system.*

raw data. The data analysis software keeps track of the number of 2π increments which occur in the phase scans and removes the ambiguities.

Tank phase is varied over approximately 360 degrees for at least two reasons. First of all, more complete comparisons between theory and experiment can be made. Secondly, verification can be made that the beam phase at 360 degrees of tank phase equals the beam phase at 0 degrees of tank phase. If the beam phases are equal at each extreme of tank phase, we can be sure that the software has properly tracked any 2π jumps in beam phase readings due to I&Q demodulator periodicity.

A special application program designed within the framework of the Fermilab ACNET accelerator control system, has been written to control and analyze the phase scans. After raw demodulator signals have been collected and converted to beam phase and tank phase, the operator can shift the whole phase-scan curve continuously along the tank-phase axis, and in 2π phase increments along the beam-phase axis.

The movement of the phase-scan curve follows the movement of a cursor placed directly on the graph. The cursor movement is controlled using a mouse. This provision allows the operator to manually line up the curve as closely as possible with a target curve that is superimposed on the graph of beam phase versus tank phase. The target curve is generated from the theory using design values for electric field and input beta for the tank.

Once the best manual curve fit to the target curve is obtained, a least-squares procedure is implemented to find the theoretical curve which best matches the measured data. The program first requests that the operator select up to 20 points along the phase-scan curve. The fitted curve will be through these selected points. With manual selection of points, the operator can avoid curve fitting to particularly noisy regions or to regions where there may be beam loss. He is also free to select points in portions of the curves that are particularly sensitive to variations in electric field and input beta. By doing so, accuracy can be improved.

For least-squares curve fitting, the subroutine, MINUIT, from the CERN numerical library, is used. Three variable parameters are used in MINUIT. These include tank electric field, input beta, and offset of the measured tank phase. When a least-squares fit has been found, the program shifts the measured data by the calculated tank phase offset, and draws the theoretical least-squares curve through the measured points. The electric field and input beta derived from the least-squares fit are printed.

Finally, a marker appears on the phase-scan graph at the position of the current tank phase setting. The marker actively follows any tank phase adjustments. The operator can now adjust the tank phase to the appropriate position along the phase-scan curve. If the electric field and input beta equal design values, the proper tank phase setting will be zero on the phase scan curve, since we have referenced all phases to the design phase in the theory. Tank phases different from zero may be appropriate if electric field and input beta are not equal to design.

III. PHASE SCAN SIGNATURES

Figure 2 is an example of the phase-scan data that are obtained on tank 6 of the drift-tube linac at Fermilab. The faint solid line in the figure is the least-squares curve fit to the measured data. The fitted curve is nearly indistinguishable from the measured points in figure 2. The

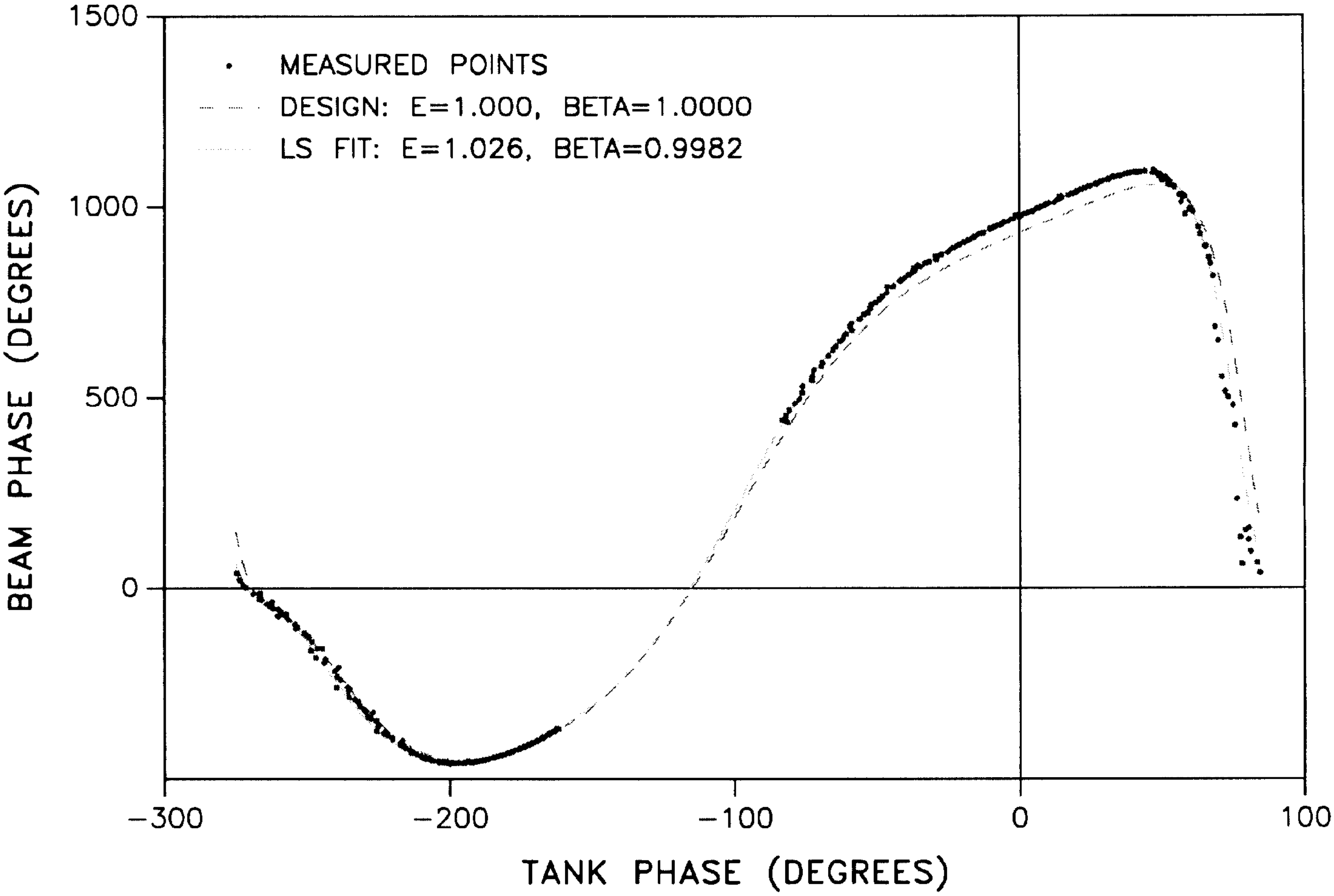

Figure 2. *Phase-scan curves for tank 6 of the Fermilab drift-tube linac. Beam phase is measured 16.96 meters past the end of tank 6. Tank electric field (E) and beta (at input) are referenced to design values.*

dashed line in figure 2, which deviates from the measured points, is the design curve. From the least-squares fitting procedure, the difference between design and measured phase-scan curves indicates that the tank electric field is 2.6% above the design value and the input beta is 0.18% below design.

IV. REFERENCES

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