PHASE SCAN SIGNATURE MATCHING FOR LINAC TUNING

T.L. Owens, M. Popovic, K. Junck, T Kroc, E. Mccrory
*Fermi National Accelerator Laboratory**
P.O. Box 500
Batavia, Illinois 60510

Abstract

A relatively simple method for linac tuning has been devised, tested and used on the Alvarez and side coupled linacs. Tank or Module phase is varied over 360 degrees while the phase of signals from strip-line beam monitor is measured. 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, and the input and output betas of the tanks/modules. Early experiments on tanks 4-7 of the Alvarez linac have demonstrated the feasibility of the technique. Recently this method was used for commissioninig of the Fermilab upgraded linac.

Introduction

The phase-scan signature for a linear accelerator (linac) tank is a curve which represents the phase of a radio-frequency (rf) signal induced by the linac beam in a beam monitor, such as a stripline detector, as a function of the phase of the electromagnetic fields within the linac tank. Accurate and detailed comparison of broad phase-scan signatures with theory was suggested at Fermilab in 1990 [1] as a means of accurately determining tank field amplitude, phase, and input beta. A similar idea was also proposed independently at the Los Alamos National Laboratory [2]. The phase-scan signature matching technique is used to find all tuning parameters needed to center the beam in longitudinal phase space, including tank electric field, tank phase and the beta of the beam at the entrance of the tank. Originally, phase-scan signature matching was used on the drift tube ion linac at Fermilab [3, 4]. In preparation for commisioning of the Fermilab High Energy Linac, phase-scan signature matching was suggested as a means of coarse-tuning of the side coupled modules. It was assumed that the classical delta-t procedure [5, 6] would be used for fine tuning.

Detailed analysis and experiments using the phase-scan signature matching technique reveal that accuracies are high enough that acceptable linac tuning is possible using only this techique. Our 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.

Phase-scan signature matching is illustrated schematically in Fig. 1.

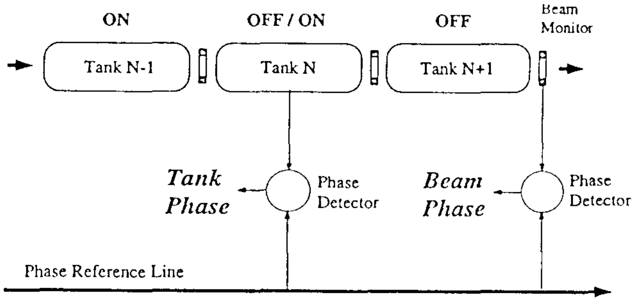


Figure 1.

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 rf signal (beam phase) at a downstream monitor is then recorded. This zero-power, unaccelerated beam phase reading is subtracted

---

*Operated by the Universities Research Association under contract with the U. S. Department of Energy from all subsequent, accelerated beam-phase readings. The theoretical accelerated beam-phases are similarly referenced to the phase of an unaccelerated beam. The beam pickup can be immediately downstream of the tank being measured (if there are space constraints, like at the end of the linac), or, for higher accuracy, pickup downstream of the next tank can be used. Radio-frequency power is applied to tank N and the beam-phase at the beam monitor is recorded as a function of the phase of the accelerating fields within tank N. Tank N phase is varied over approximately 360 degrees during this procedure. The tank phase signal is derived from direct measurements of tank fields using pickup loops within the tanks. Phase detection for both the beam signal and the tank field is performed using I&Q demodulators.

Phase-Scan Theory

The principle parameter that must be calculated is the phase of the beam-induced rf signal (beam phase) at the beam monitor which is located after the tank being tuned. Beam phase is directly proportional to the time of arrival of the beam at the monitor. In this sense, the present measurements are time of flight measurements. Since it is convenient and accurate to measure phase changes at a fixed position using a single phase monitor, the phase difference between unaccelerated and accelerated beam at fixed positions will be obtained in the following calculations. The difference between unaccelerated beam phase and accelerated beam phase is a function of beta and beam phase at the input to the tank, and accelerating field within the tank. This phase difference is given by,

$$\Delta\Theta = \omega\left(\frac{D_{AB} + D_d}{v_a}\right) - 2\pi N_c - \Phi_B + \Phi_a$$

where D_{AB} is the length of the tank, D_d is the distance from the end of the tank to the beam phase monitor, v_a is the beam velocity at the entrance to the tank, N_c is the number of cells within the tank, Φ_B is the beam phase with the rf on at the exit of the tank, and Φ_A is the beam phase at the entrance of the tank. Beam phases at the entrance and exit of the tank are referenced to the phase of the rf field within the tank. The longitudinal dynamics used to calculate quantities on the right side of Eq. 1, utilize a "thin lens" approximation [7]. Using this approximation, the beam drifts freely to the center of each cell of the tank. In the center of the cell, a step change in beam velocity is calculated and the beam drifts from the center of the cell to the cell exit with the new velocity. A step change in phase, which contributes to the phase at the exit of the cell, also occurs at the center of the cell. The procedure is repeated for each cell of a tank to yield output beta and beam phase for the entire tank as a function of input beta and beam phase. The full set of equations which govern these dynamics are given in referece [4].

Phase-Scan Experiments

Figure 2 is a tipical example of the phase-scan data that are obtained on Module 2 of the side coupled linac at Fermilab.

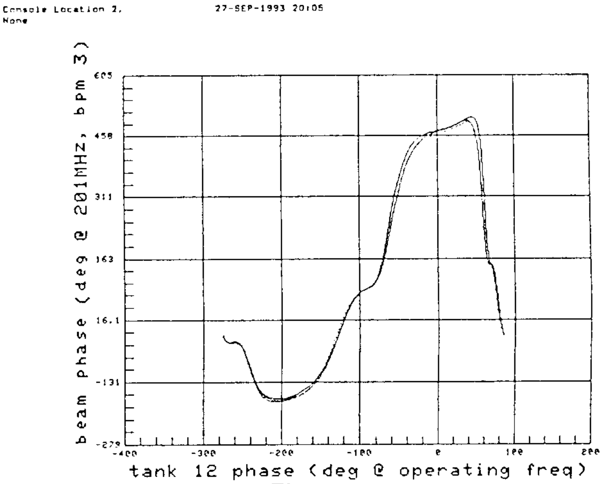
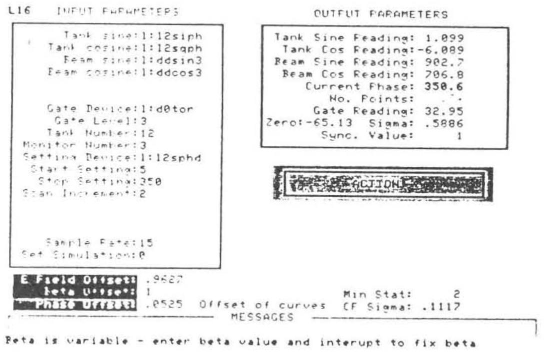


Figure 2.

Module 2 is approximately one-thirds of the way down the linear accelerator. For Module 2, design input beta is 0.5094 and design output beta is 0.5554. The average accelerating gradient is 7.82 MV/m. The distance from the end of Module 2 to the beam monitor is 0.3655 meters. The solid line in Fig. 2 is the least-squares curve fit to the measured data. On the scale presented in Fig. 2, the measured data exhibits very little noise. The fitted curve is nearly indistinguishable from the measured points. The dashed line in Fig. 2 is the design curve. The deviation in the design curve from the fitted curve is adequate to clearly distinguish the two curves. Information presented in Figure 3. are the data the operator sees in the process of setting the module parameters. In this example, Module 2 electric field and input β are expressed as fractions of design values. From the least-squares fitting procedure, the difference between design and measured phase-scan curves indicates that the tank electric field is 3.7% below the design value, the input beta is on the target value. Other information presented to the operator shows precisely where the tank phase must be set[4].



```
L16     INPUT PARAMETERS                        OUTPUT PARAMETERS

         Tank sine:1:12siph             Tank Sine Reading: 1.099
       Tank cosine:1:12sqph              Tank Cos Reading:-6.089
         Beam sine:1:ddsin3             Beam Sine Reading: 902.7
       Beam cosine:1:ddcos3              Beam Cos Reading: 706.8
                                            Current Phase: 350.6
                                               No. Points:
       Gate Device:1:d0tor                   Gate Reading: 32.95
        Gate Level:3                  Zero:-65.13  Sigma: .5886
       Tank Number:12                         Sync. Value:     1
    Monitor Number:3
    Setting Device:1:12sphd
     Start Setting:5                         ACTION
      Stop Setting:350
    Scan Increment:2

       Sample Rate:15
    Set Simulation:0

E Field Offset: .9627
   Beta Offset: 1                              Min Stat:     2
  Phase Offset: .0525  Offset of curves   CF Sigma: .1117
------------------------ MESSAGES ------------------------
Beta is variable - enter beta value and interupt to fix beta
```

Figure 3.

Phase-Scan Errors

Simulations are used to estimate practical limits on the accuracy of the phase-scan signature matching procedure. A simulated experimental phase-scan curve is generated from theory by adding a random phase fluctuation to the tank phase, and inputting this randomly fluctuating tank phase into the theoretical calculation of beam phase. A second random phase fluctuation is added to the calculated beam phase. The effects of random fluctuations in phase readings, which constitute the principal source of random error in the phase-scan technique, can thereby be determined. It is assumed that there are no sources of systematic error. The simulated phase-scan curves are input directly into the data acquisition program used to gather and analyze experimental phase-scans, substituting for real phase-scan measurements. Random errors of ±1 degree induced in the tank and beam phases have produced only fractional percent errors in the input beta and field amplitude in the simulations.

Conclusions

These results establish the viability and accuracy of the phase-scan signature matching technique for setting the important parameters required for linac tuning. Experimental tests on the Fermilab drift-tube linac and application on the newly installed side-coupled structure have demonstrated the speed and relative simplicity of the technique. In our first attempts to apply phase-scan signature matching on the new side-coupled linac, we were able to tune all seven modules in less than 20 hours. This is a remarkable achievement considering the fact that tune settings were initially far from design before the techique was applied. It now takes only a few minutes to check and correct, if necessary, the tuning of individual modules. We believe that the phase-scan signature matching techinque has major advantages over other tuning techiques and can be readily applied to nearly any ion linac.

References

[1] T.L. Owens, "Phase and Amplitude Tuning Procedures for the Fermilab Linac," Fermilab Report TM-1713, Jan., 1991.

[2] F. W. Guy and T. P. Wangler, "Least-Squares Fitting Procedure for Setting RF Phase and Amplitude in Drift-Tube-Linac Tanks," IEEE Particle Accelerator Conference, May 6-9, 1991, pp. 3056-3058.

[3] T. L. Owens and M. B. Popovic, "Phase-Scan Signature Matching for Linac Tuning," Fermilab Report LU-186, Nov. 18, 1992.

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

[5] T. L. Owens and E. S. McCrory, "The Delta-T Tuneup Procedure for the Fermilab Linac Upgrade," ibid, pp. 3064-3066.

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

[7] 9. B. Schnizer (1971), Part. Accel, 2, pp. 141-147.