The Delta-T Phase Scan Problem for SNS CCL Module #4.

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Introduction

During the initial operation of the SNS linac (commissioning), it will be necessary to establish the optimum settings for the phase and amplitude of the RF fields in each of the 4 modules of the coupled cavity linac (CCL). It is unlikely that these 8 quantities can be set close enough to their design values by direct field measurements alone to provide satisfactory performance.

This note explores the suitability of using the delta-t method, developed at LAMPF [1,2] and widely used elsewhere, to empirically determine the optimum settings for the SNS CCL. After the SRF linac is installed, space for delta-t diagnostics is very limited. Delta-t measurements are required for turn-on following periodic shutdowns.

. The purpose of this note is to simulate delta-t commissioning measurements on CCL module #4. For details on the delta-t method, see [1,2]. Module 4 was selected for simulation in part because it is very similar to LAMPF module 5, and because the commissioning of CCL module #4 is made more difficult by not having sufficient drift distance after the module for establishing an adequate baseline for determining the output beam velocity.

The delta-t method uses the beam-off minus beam-on time delay differences for two beam RF phase pickups, labeled B and C, at the end of the module being commissioned, and a few meters downstream of the end of the module respectively, to determine the optimum settings of the module RF phase and amplitude. The equations for the time delays (delta-t's) as a function of RF phase, RF amplitude and input energy variations, and specific simulations for the commissioning of LAMPF, are derived in the references [3].

This simulation shows the effect of shortening the B-C beam phase pickup separation downstream of module #4 on the ability to determine the correct amplitude and phase.

Simulation Model

SNS CCL module #4 is approximately 15.5 meters long, and accelerates the beam from 157.2 MeV to 185 MeV in 12 "segments", each comprised of 8 RF cells in a magnetic lattice half-period 6.5 $\beta\lambda$ long at 805 MHz. This simulation uses a single RF cell (rather than 8) to simulate each segment. Furthermore, the synchronous phase is fixed at –28 degrees in every segment, and the energy gain is equalized in each segment.

The synchrotron phase advance in CCL module #4 is about 250º and its length is 15.5 meters, thus very similar to LAMPF module #5 (the first CCL module at 100 MeV). For this reason, the delta-t simulation for CCL module #4 should be very similar to LAMPF module #5, even though the beam energy in CCL module #4 is somewhat higher.

Figure 1 shows a simulation of a variable phase delta-t scan of LAMPF module #5 using LAMPF parameters in the present model. The horizontal axis in the figure is *dTB*, the *deviation* of the time delay *change* from the design beam value in a beam phase detector "*B*", located at the end of module 5, when module 5 is turned on and off.. Both the "*B*" and "*C*" phase measurements are made relative to stable phase references. The vertical axis in the figure is *dTC*, the *deviation* of the time delay *change* from the design beam in a beam phase detector "*C*", located 15.2 meters downstream from the end of module 5, when module 5 is turned on and off. Module #6 is always off. The design beam is a beam with the synchronous input energy Ws, with the design module #5 RF amplitude (A=1.00), and synchronous input phase (phi=phis). Note that the time delay measurements are *deviations* of the measured *changes* (beam off – beam on) from the *expected changes*, and do not require any absolute time difference measurements. Compare this figure to Fig. 7 of [1]. The agreement between this simulation and Figure 7 implies that the present linac structure model is satisfactory for simulating delta-t variable phase scans in the SNS CCL. Except for the input and output energies, the overall length of the module, and the synchronous phase angle, the models used for LAMPF module #5 and SNS CCL module #4 are identical.

Figure 2 shows a simulation of variable phase delta-t scans of SNS CCL module #4. Compare this Figure to Fig. 1. In this figure, the B-C drift distance is set to 16 meters, and each red line represents a phase scan from phi=(phis-5) degrees to (phis+5) degrees, with other parameters held constant. The five clustered phase scans represent phase scans at five RF amplitude settings, from 0.95 to 1.05 times the synchronous value. The five clusters represent 5 different values of the input beam energy, ranging from Ws – 0.2 MeV to Ws + 0.2 MeV. During a delta-t measurement, the input beam energy is not changed, even though it may not be the energy of the design beam.

Figure 3 is the same as Figure 2, except that the horizontal and vertical scales are changed from ± 200 ps to ± 80 ps. The three phase scans in each cluster represent an RF amplitude range of ±2%, the amplitude limits for the SNS CCL. The three blue lines represent an input phase offset range of ±2º, the phase offset limits for the CCL. The five clusters represent five different input beam energies. The B-C separation is 16 meters.

In a delta-t scan, phase scans are performed for various RF amplitudes for a specific fixed input beam energy, and the *dTB* and *dTC* values are set within the area bracketed by the 3 blue lines. The slope of the phase scan line must be within the cluster of the 3 red phase scan lines for that specific input beam energy[4]. The intercept of the phase scan line with the center blue line depends on the deviation of the input beam energy from the synchronous input beam energy *Ws*. To achieve the required accuracy for the case depicted in Figure 3, the apparent resolution requirement on *dTB* and *dTC* measurements must be of the order of ±10 ps.

For the initial commissioning of CCL module #4, neither SRF module #1 nor the 2-meter-long CCL-to-SRF transition, which includes the permanent beam diagnostics and special vacuum pumping systems, will be installed. For initial commissioning, a temporary drift and beam stop will be installed, and removed prior to the installation of SRF cryomodule #1. The B-C separation for initial commissioning could be of the order of 4 meters.

Figures 4 differs from Fig. 3 only in that the B-C pickup separation is reduced to 4 meters from 16 meters. The resolution requirement to achieve the ±2% and ±2º limits for the amplitude and phase setpoints appears to be about ±2 ps.

After CCL commissioning is complete, and cryomodule #1 of the SRF linac is installed, there is only about 1.5 meters of useful space between the CCL and the SRF linac for permanent diagnostics, including phase pickups B and C, which will be needed for tuneup after periodic shutdowns.

Figure 5 is the same as Figure 3, except that the B-C separation is reduced from 4 meters to 1.5 meters, and the *dTB* and *dTC* scales are reduced from ±80 ps to ±20 ps..It is apparent that the time delay resolution must be of the order of 0.5 ps to make delta-t measurements. Considering that 0.5 ps represents only about 0.1 mm of change of cable length, these phase measurements may be very difficult.

One option may be drifting the beam through SRF cryomodule #1 to a beam pickup between cryomodules. Because both CCL module #4 and cryomodule #1 will be off for part of the measurement, the beam cannot be accelerated in the SRF linac. Furthermore, with CCL module #4 off, the beam may debunch before reaching the linac zero-degree beam stop. This may require a beam stop in a beam box between cryomodules. This is not a very attractive option.

Conclusion.

The separation of the B and C pickups between the CCL and the SRF linacs is probably not adequate to perform tune-up delta-t measurements after SRF cryomodule #1 is installed. Alternative methods for performing tune-up measurements need to be explored.

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[1] K. R. Crandall and D. A. Swenson, "Side-Coupled cavity Turn-On Problem", MP-3-98 (February 9, 1970).

[2] K. R. Crandall, "The Delta-t Tuneup Procedure for the LAMPF 805-MHz Linac",LA-6374-MS (UC-28) (May 1976).

[3] See for example, ref[2], Eqns (8) and (9).

[4] This description is based on the *slope method* for setting amplitude and phase, described in [2]. The other method described in [2] is the *output energy change method*. Both methods have essentially the same time resolution requirements.

Figure 1. Simulation of variable phase delta-T curves for LAMPF module 5. Compare to Fig. 7 of Ref[1].

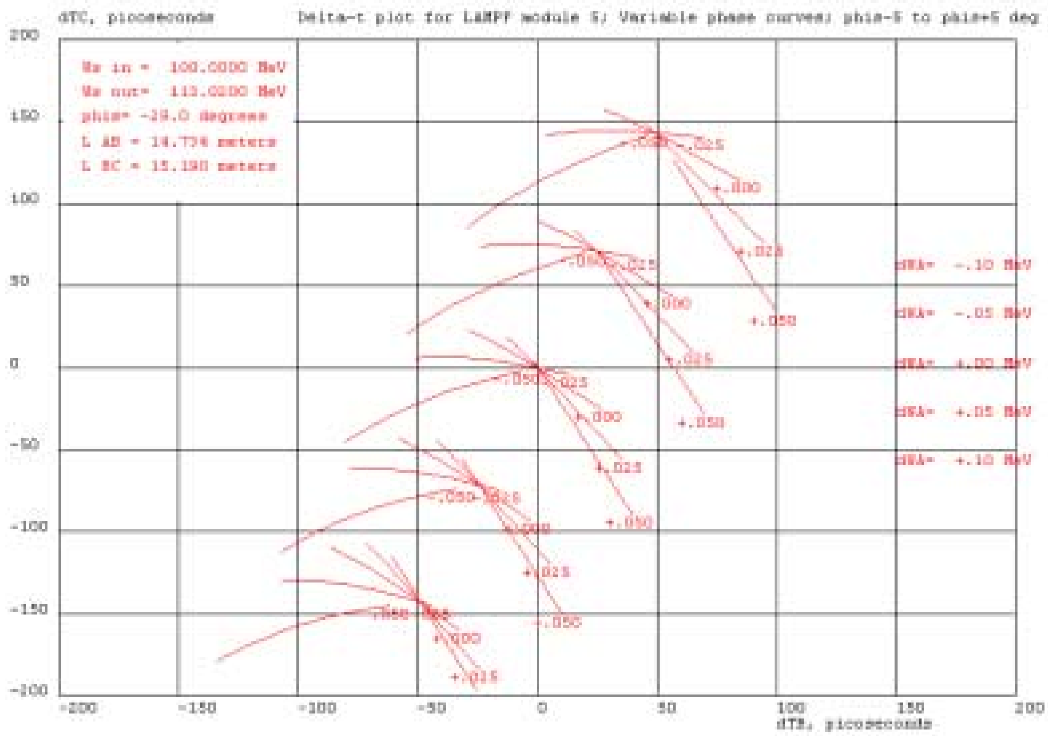

Figure 2. Variable phase delta-t curves for SNS CCL module #4.

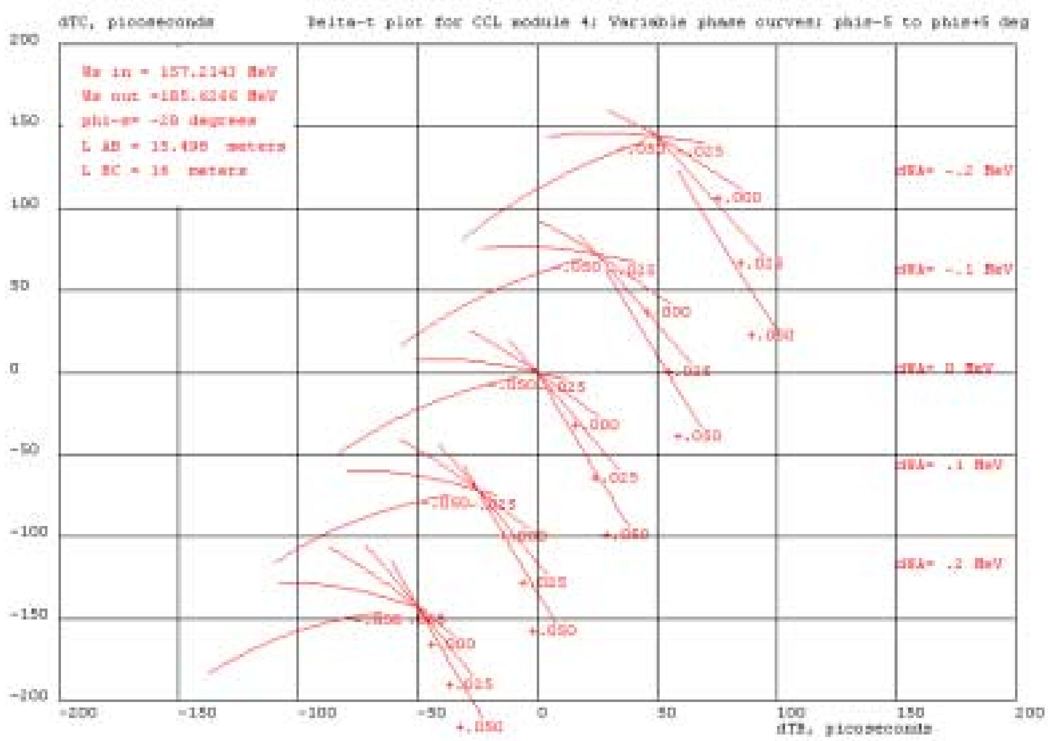

Figure 3. Same as Fig 2, except *dTB* and *dTC* time scales are 2.5 times smaller. The three red lines represent ±5º phase scans with a maximum RF amplitude offset of ±2%. The three blue lines represent a maximum phase offset of ±2º. The B-C separation is unchanged.

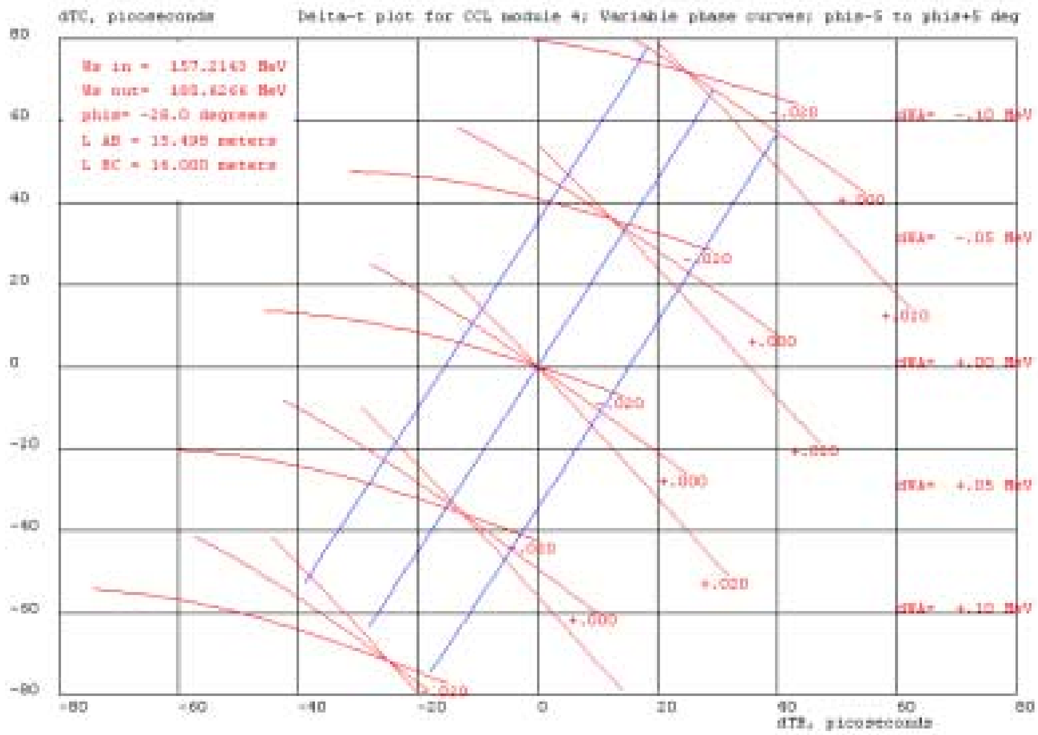

Figure 4. Same as Figure 3, except the B-C pickup separation has been reduced to 4 meters from 16 meters.

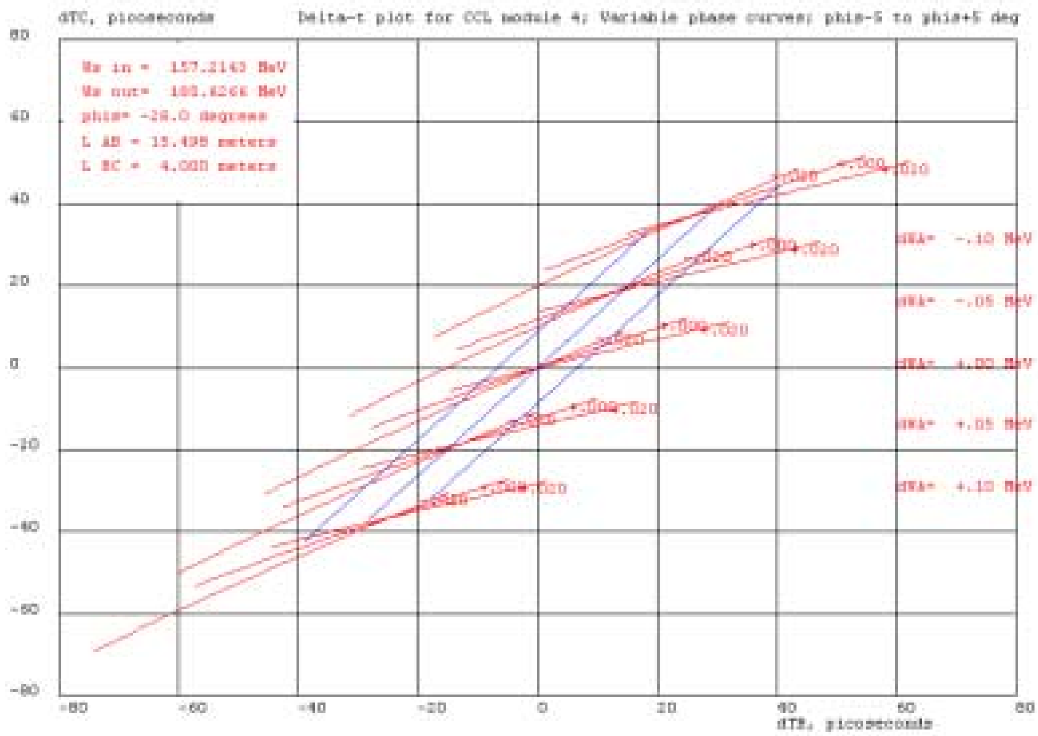

Figure 5. Same as Figure 4, except the B-C separation is further reduced to 1.5 meters from 4 meters, and the dTB and dTC scales are reduced to ±20 ps from ±80 ps..