PASTA – AN RF PHASE SCAN AND TUNING APPLICATION*

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Abstract

To assist the beam commissioning in the Spallation Neutron Source (SNS) linac, a general purpose Radio Frequency (RF) tuning application has been written to help set RF phase and amplitude. The method involves varying an Rf cavity amplitude and phase settings over a fairly large range and comparing the measured downstream beam phase response "signatures" to model predictions. The model input for cavity phase, cavity amplitude, and the beam energy are varied to best match observations. This scheme has advantages over other RF tuning techniques of not requiring intercepting devices (e.g. Faraday Cups), and not being restricted to a small linear response regime near the design values. The application developed here is general and can be applied to different RF structure types in the SNS linac. Example application for the SNS Drift Tube Linac (DTL) and Coupled Cavity Linac (CCL) structures will be shown

INTRODUCTION

RF linac structures are often tuned by performing a scan of the RF phase and amplitude, and comparing measured beam arrival times (or phase) at downstream locations. Measured phases are compared to model predicted values and the model input amplitude and phase that best match the measured values can be used to calibrate the RF system with the beam, and determine the correct RF settings. This general approach has been used for decades in many places. The Δ-T method pioneered at LANL [1,2] uses this approach, and it has been adopted by others [3-5]. The Δ-T approach assumes a linear response of measured quantities with the RF variations, and hence is only valid for a small region about the design phase and amplitude. With the advent of faster computers, more general "signature matching" techniques evolved, for example as in Ref. 6. This technique does not have a linear response restriction and tend to be more general. In particular it has the advantage of not requiring a good guess of phase and amplitude for the method to work. In addition other methods using intercepting devices exist for setting linac phase and amplitude [7].

At SNS we have developed a signature matching application to help in the setting of the RF phase and amplitude for warm linac structures. The application follows the methodology described in Ref. 6. The application developed at SNS is described, and results for setting the RF phase and amplitude for the SNS linac DTL and CCL structures are shown.
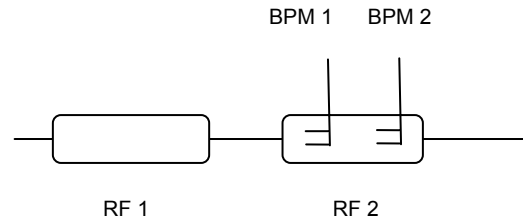
PASTA APPLICATION

Fig. 1. Schematic of the device layout used in the RF phase and amplitude measurement and setting procedure.

Methodology

The device setup used in the RF setting procedure is depicted schematically in Fig. 1. In the SNS warm linac, beam phase is provided by Beam Position Monitors (BPMs) which are imbedded within RF structures. When tuning an RF structure, the downstream RF structure containing the beam phase detection BPMs is turned off so that the beam simply drifts after exiting the RF structure being tuned. The phase in the RF structure being tuned (ϕ_{rf}) is varied, and phases at the downstream BPMs (ϕ_{bpm1} and ϕ_{bpm2}) are monitored. The phase ϕ_{rf} is the RF klystron phase. This procedure is modeled using the equations presented in Ref. 6, which have been incorporated into the XAL application programming online model [8]. The model produces calculated values for the BPM phases ($\phi_{bpm1calc}$ and $\phi_{bpm2calc}$) as a function of the beam synchronous phase (ϕ_s). The task is to match the modeled values with the measured. We use phase difference between BPMs in this matching, i.e. we minimize the difference between (ϕ_{bpm2}- ϕ_{bpm1}) and ($\phi_{bpm2calc}$- $\phi_{bpm1calc}$) over the range of scanned ϕ_{rf}. Three quantities are varied in this matching exercise:

$\phi_{offset1} = \phi_{rf}$ - ϕ_s ,
W_{in} = input beam energy to the RF structure, and
V_{rf} = the RF voltage during the scan.

The measured phase differences are spline fit, so that the measured and calculated phase difference can be compared at any point. This procedure can be done for up to three different RF amplitude settings (i.e. simultaneously match three different phase signatures). It is important to have a good knowledge of the BPM relative positions, since we use phase differences between BPMs. But the distance between the RF structure being tuned and the BPMs (which is less certain) is not important.

The approach described above does not work if there is a systematic offset in a BPM measured phase (e.g. poor BPM cable calibration of glitch in the hardware electronics). Another technique that alleviates this possibility is to normalize the BPM phases with a phase found with the tuning RF structure turned off. (This approach is standard in the Delta-T approach). In this case the quantity $\{(\phi_{bpm2} - \phi_{bpm2-0}) - (\phi_{bpm1} - \phi_{bpm1-0}\}$ is matched to $\{(\phi_{bpm2calc} - \phi_{bpm2calc-0}) - (\phi_{bpm1calc} - \phi_{bpm1calc-0})\}$, where the "-0" in the phase subscript refers to the phase values with the RF off. Another advantage of this method is that it can be used if only one BPM is available for phase measurement, without precise knowledge of the RF and BPM positions.

Application

A software application called PASTA has been written to perform RF phase setting using the signature matching method. It uses the XAL framework [8]. There are 3 basic parts: device selection, scan control and analysis. A device selection panel allows user selection of an RF structure to tune and 2 BPMs to use for measurement. The locations of the chosen devices, RF structure geometry and Transit Time Factor parameterizations (as a function of beam energy) are all initialized from a database configuration.
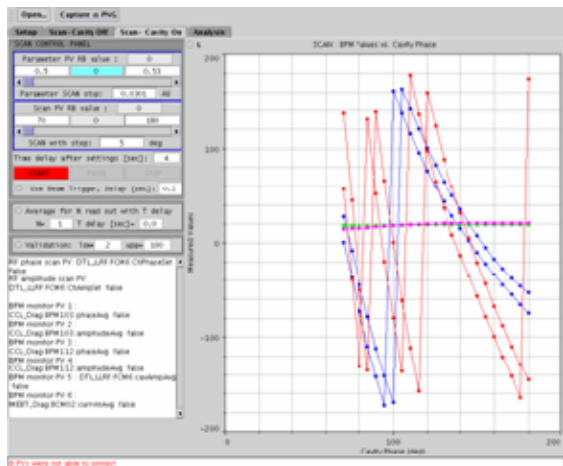
Fig. 2 The panel of the PASTA application, that controls data acquisition, and displays measured data.

The scan control panel is shown in Figure 2. This uses an existing scanning package component of the XAL framework. Measured quantities include the BPM phases and amplitudes (the amplitude indicates the intensity of the beam bunch – a function of current and bunching). We use the measured amplitudes to suppress comparison with the model when the beam intensity falls below a specified threshold (typically 5 mA), below which measured phases are suspect. Note the display of raw measured values somewhat resembles wet pasta.

The PASTA analysis panel is shown in Figure 3 (for DTL tank 1). This panel includes control of the matching parameters, displays the matching results, and indicates the suggested RF setpoints. The plot shows the measured BPM phase difference (lines) and the calculated BPM

phase difference (dots) vs. RF phase, after a solution is found. In this case the RF phase is scanned for ~ 50 degrees at 2 amplitude settings. In other structures, scans can be done for > 100 degrees, as opposed to the typical 10 degree scan range used in the Δ-T method. As often the case, a non-linear BPM phase difference response to the RF phase swing over this range is evident. These "unique" nonlinear features make the matching easier.
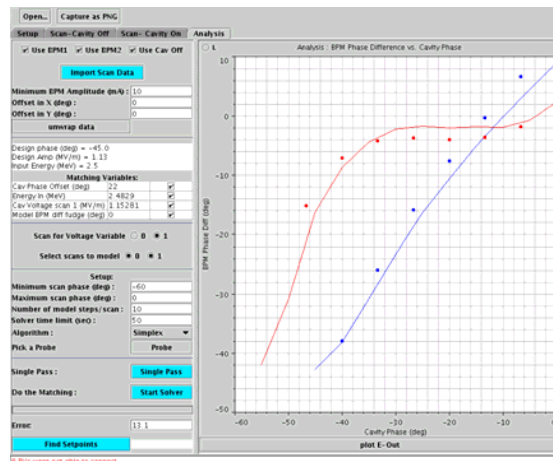
Fig. 3 The analysis panel of the PASTA application.

RESULTS

PASTA has been used to tune the SNS DTL and CCL structures. Figure 4 shows the results from matching for DTL tanks 2-6 and CCL modules 1-3 from the same RF setup period (the DTL tank 1 tuning for this set is shown in Figure 3). The matching shown in the figures is from the tuning performed in the control room. Note that there is often a few degrees difference between the measured and modeled BPM phase differences in the vicinity of the suggested RF set point. The procedure has been sped up subsequently, so better matches are now possible. Note that each RF structure produces a unique BPM phase difference vs. RF phase "signature". With the large RF phase scan ranges here, BPM phase differences often cross $\pm 2\pi$ intervals, so care must be taken to unwrap the data appropriately at these points.

For the CCL cases shown in Figure 4, a Δ-T method [5] was subsequently used as a check on this method. The suggested phase setpoint agreement between the two methods varied between 0 and 11 degrees, and the suggested amplitude setpoint agreement varied between 0 and 5%. In any case, using the PASTA as an initial guess for the Δ-T method greatly reduced the number of iterations required for the D-T method convergence.
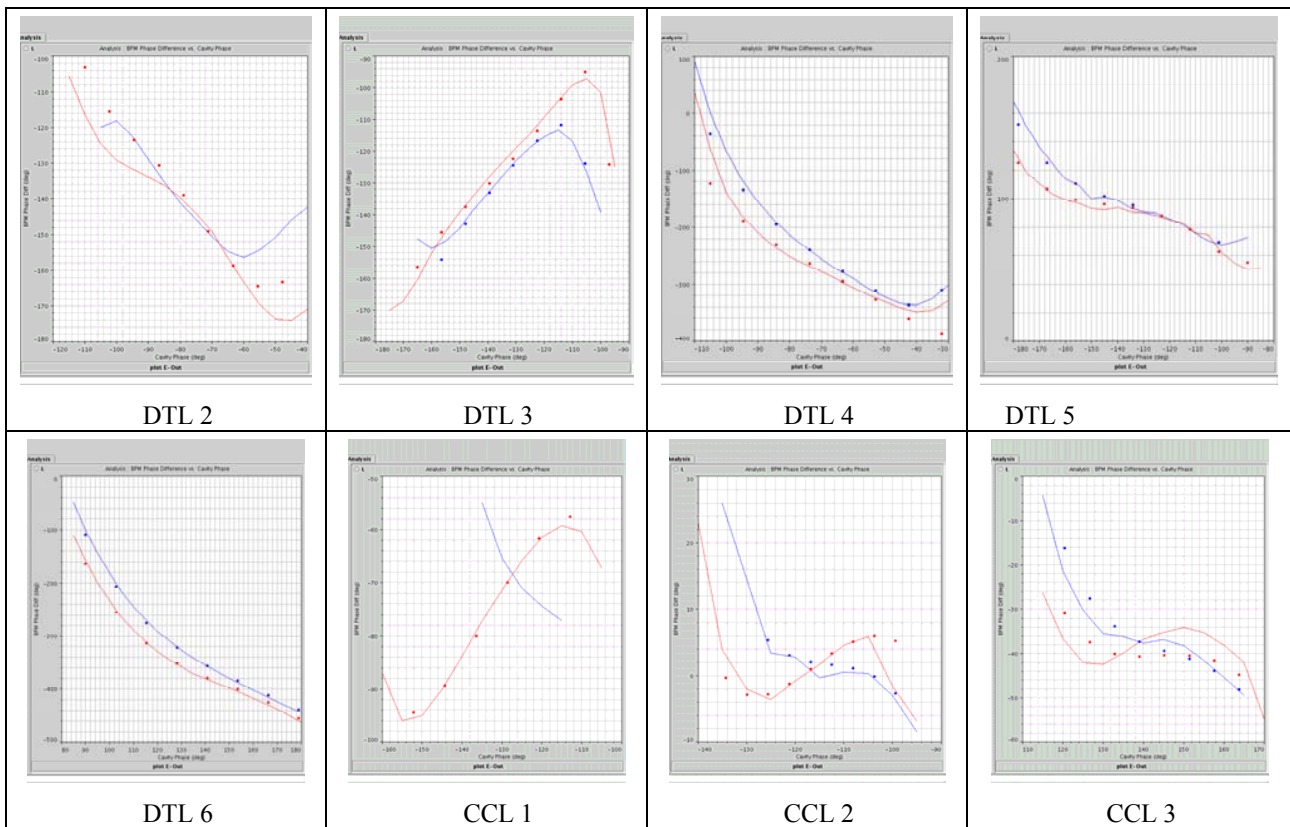
Figure 4. Composite view of the model vs. measured BPM phase signature match for SNS DTL and CCL structures.

In addition to solving for beam energy at the RF structure entrance, the calculated exit energy is also available. A check on the consistency of the PASTA phase setting, is to compare the calculated beam exit energy for an RF structure, with the calculated input energy solved for at the following RF structure. Table 1 shows values for these quantities (as well as the design exit energy) , for the cases shown in Figure 3-4. With the exception of DTL5, there is generally agreement to better than 100 keV.

RF Cavity	W_{in} (MeV)	W_{out} (MeV)	W_{out}design (MeV)
DTL1	2.48	7.51	7.52
DTL2	7.56	22.83	22.89
DTL3	22.90	39.74	39.77
DTL4	39.82	56.45	56.54
DTL5	56.78	73.30	72.52
DTL6	72.52	87.05	86.83
CCL1	86.91	107.12	107.16
CCL2	107.10	131.25	131.14
CCL3	131.07	157.20	157.21

SUMMARY

A signature matching phase method is implemented for warm linac RF setting at the SNS. Use during initial beam commissioning is promising, and we hope to improve the accuracy and easy of use as we gain experience using it.

REFERENCES

[1] K.R.Crandall and D.A.Swenson. Side Coupled Linac Turn-on Problem. LANL Report MP-3-98, February, 1970.

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

[3] T.J.Owens, E.S.McCrory. The Delta-T Tuneup Procedure for the Fermilab Linac Upgrade. Proc. Of 1991 IEEE Particle Acc. Conf., San Francisco, Ca., May 1991.

[4] S.V.Dvortsov et al. The Δt Procedure Application at the INR Linac. Proc. of the EPAC-3 Conf., Berlin, March, 1992.

[5] A. Feshenko, et. al., "Development and Implementation of a Δt procedure for the SNS Linac", these proceedings

[6] T.L. Owens, M. B. Popovic, E. S. McCrory, C. W. Schmidt, L.J. Allen, "Phase Scan Signature Matching for Linac Tuning", Particle Accelerators, 1994, Vol 98, p. 169.

[7] D. Jeon, et.al., Proc. of the 2002 LINAC conference (Gyeongju, Korea, 2002), p.368

[8] J. Galambos, et. al., "XAL Application Programming Structure", these proceedings