SOFTWARE TOOLS FOR COMMISSIONING OF THE SPALLATION NEUTRON SOURCE LINAC *

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Abstract

The Accelerator Physics group at the Spallation Neutron Source (SNS) has developed numerous codes to assist in the beam commissioning, tuning, and operation of the SNS Linac. These codes have been key to meeting the beam commissioning milestones. For example, a recently developed code provides for rapid retuning of the superconducting Linac in case of RF stations going offline or coming online. Highlights of these "physics applications" are presented.

INTRODUCTION

The Spallation Neutron Source linac is designed to produce a pulsed (60Hz) beam at 1000 MeV with an average power of 1.4 MW. This will be both the highest energy proton accelerator and highest power proton linac when fully operational. The SNS Linac consists of traditional copper sections for low energy acceleration (up to 186 MeV) and a Super-conducting Cavity Linac (SCL) for the majority of the beam acceleration (186 MeV to ~ 1000 MeV). In addition to the usual methods such as beam steering, a number of new techniques have been developed for tuning the SNS linac. These include methods for setting both the warm and superconducting cavity RF phase and amplitudes. An unexpected experience of the SCL is that frequent adjustment of cavity gradients are needed, depending on cavity availability and operating condition. We have developed tools to rapidly adjust the machine setup depending on the SCL configuration, as discussed below.

The software used here is developed with the XAL application framework infrastructure [1]. A key component of XAL is an online model [2], namely a beam tracking model that can be configured from the machine state. All references to model results herein refer to the XAL online model.

WARM LINAC CAVITY SETUP

The warm linac structures are Drift Tube Linac (DTL) and Coupled Cavity Linac (CCL) structure types. These consist of rather large resonant structures containing many (up to ~ 100) individual gaps driven by a single RF power source. The RF gaps are designed to accommodate a precise acceleration path, and hence the RF field and phase relative to the entrance beam must be set to the exact design values. The historical method for doing this is the Delta-T approach [3] which relies on a linear approximation valid for a small phase range near the design value. Sometimes it is difficult to find the right starting range for this technique to converge. We use the more general phase signature matching method [4], which involves scanning the RF phase over a wide range, measuring variation of the arrival time of beam downstream, and matching the observations with a longitudinal tracking model within an optimization framework. We have coded the cavity scanning and data analysis portions of this operation in an application we call PASTA (Phase and Amplitude Scanning and Tuning Analysis) [5]. With modern computers the use of longitudinal tracking within an optimization framework described above is not a significant part of the procedure. Output from this sort of analysis is the cavity field, the cavity phase relative to the beam, and the beam input and output energies. Figure 1 below shows a snapshot of a typical completed DTL cavity setup. Each cavity has a unique response of the downstream arrival time vs. cavity phase and amplitude, which becomes easily identifiable if one ventures beyond the limited linear response regime around the design values (for the case shown, near 165 degrees).

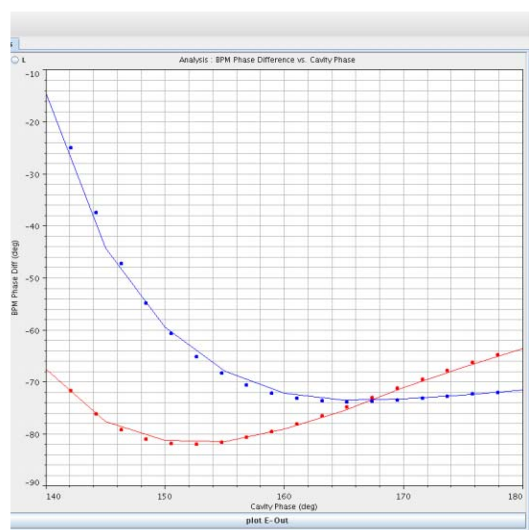

Fig. 1 The phase signature scan method result for a DTL tank (downstream BPM phase difference vs. DTL RF phase). Solid lines are measured, dots are model results, and red/blue represents different RF amplitudes. The nonlinear response on the LHS offers a unique “signature” for the model matching to meet.

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SUPERCONDUCTING LINAC APPLICATIONS

SCL Experience

One of the biggest surprises during the SNS beam commissioning was how many SCL cavities were not operated at the design values and also how resilient the beam is to this situation. Typically we have run with 5-10 out of the nominal compliment of 81 cavities powered off for various reasons. Output beam energies from the SCL linac have ranged from 560 to 1010 MeV.

EnergyManager Application

A ramification of operating the SCL linac with many different cavity voltage setups and output beam energies is a need to rapidly arrive at new transverse optics settings (i.e. quadrupole operational values). The energy manager application (Fig. 2) provides this capability. It reads in the SCL cavity operational values, performs an initial quadrupole scaling relative to the design, based on the expected revised acceleration path. It offers the user a range of further matching possibilities: which quad power supplies to vary over prescribed ranges, desired beam Twiss parameters at arbitrary positions, minimization of the deviation from the design optics etc. This procedure is used for each tune-up with a new set of cavity operational voltages. It also provides the capability to scale the other accelerator sequence magnets to the new output energy.

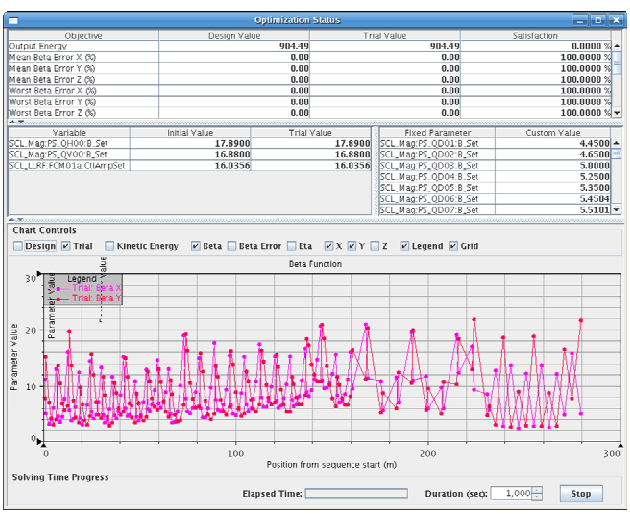

Fig. 2. A screen snapshot of the Energy-Manager application indicating some optimization figures of merits for matching, power supplies for variation and the resulting Twiss beta values along the SCL and downstream transport line.

SCL Cavity Setup

The strategy for tuning the SCL linac RF is to operate each cavity at its highest safe operable gradient, and adjust the phase relative to beam as desired. Unlike the warm linac RF structures, the SCL cavities provide acceleration over a much smaller beta range and have much fewer acceleration gaps. Each SCL cavity acts much like a single "effective RF gap kick". This simplifies the cavity phase setting procedure. We use an application called Superconducting Linac Automated Cavity Setup (SLACS) [6] to perform RF phase scans, measure downstream beam arrival response, and perform the model based analysis for each cavity. A typical result of a SCL cavity scan is shown in Fig. 3. The measured change in downstream beam phase measurements vs. the cavity RF phase is shown in the solid line. The model results are indicated as dots for the best match after solving for the input beam energy, cavity voltage and RF phase offset relative to the beam arrival. The beam phase response is almost sinusoidal, indicating an almost ideal gap response. This makes scanning and analyzing quite easy. Using this application, all the cavities can be scanned in a period of ~ 6 hours. With further automation, this setup time could be decreased, but it is not a major consideration at present. The SLACS application compiles a spreadsheet format compilation including beam energy in, energy gain, cavity voltage and klystron phase offset from the beam, for each cavity.

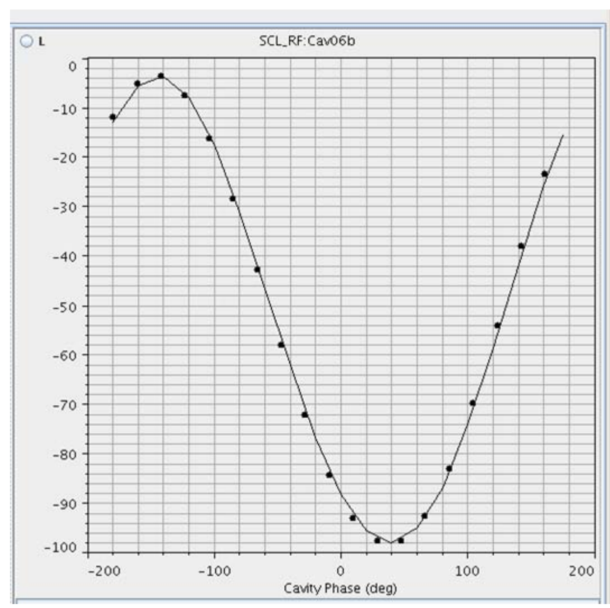

Fig. 3 Snapshot of an SCL phase scan. The downstream BPM phase difference is shown vs. the cavity phase over a 360 degree scan range.

SCL Cavity Phase Scaling

If a cavity is disabled for any reason, or its amplitude is changed by more than a few MV/m, the arrival time at the next downstream cavity is changed enough to require a retune of all the SCL cavity phase setpoints. A cavity failure upstream can result in an arrival time change downstream equivalent up to thousands of degrees. It is quite difficult to a priori predict the absolute beam arrival time (i.e. RF phase setpoint) at a cavity due to uncertainties in precise cavity position, energy gain etc. However, the perturbation in the measured beam arrival time at downstream cavities due to an upstream cavity

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failure is much less sensitive. The simple longitudinal tracking model used in XAL can predict the change in cavity phase to within a few degrees for typical uncertainties in cavity position and energy gain in a cavity [6]. Using the model predicted change in the beam arrival time, perturbations on the measured cavity phase setpoints gathered by SLACS scans discussed above are calculated with the model. The SLACS application also includes a feature to perform this phase scaling and propagate the updated cavity setpoints to the SCL cavities.

This phase scaling feature has proved useful for rapid recovery of the SCL with cavity reconfigurations. On several occasions, there has been a need to turn off multiple cavities, and simultaneously increase and/or decrease other cavity operational gradients. Although developed for recovery of single cavity failure, the scaling technique has been employed for these more serious reconfigurations. Once the new gradients are settled, it only takes seconds to calculate the new cavity phase setpoints and update the machine with the new phases.

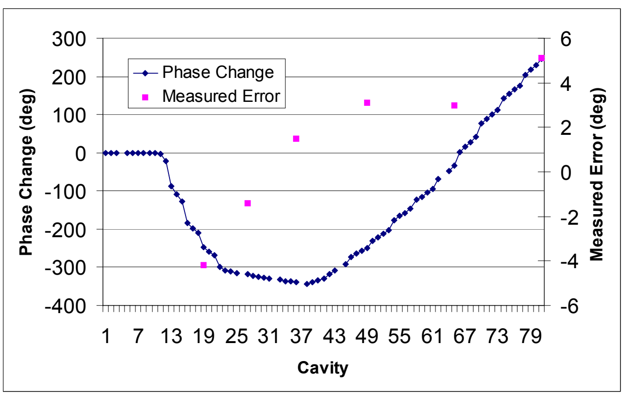

Fig. 4 Phase change (blue) resulting from reductions in 11 cavity gradients and activation of 1 previously unused cavity. Measured errors for selected cavities are indicated in purple.

The technique was tested by changing operational cavity gradients, calculating the new cavity phases, and checking the predicted cavity phase changes with beam based phase scans at selected intermediate cavity locations. Results of this check are indicated in Fig. 4, for a case when 11 cavity gradients were reduced, and one previously unused cavity was activated. Fig. 5 shows another example usage of this feature, for a case when 20 cavities (about ¼ of the total) were simultaneously changed from the gradients at which the beam based phase scans were performed (during a transition from 4.2 K to 2 K cryogenic operation). This resulted in changes in some cavity phase setpoints of over 2000 degrees. Beam operation with the new cavity setup showed no change in beam loss.

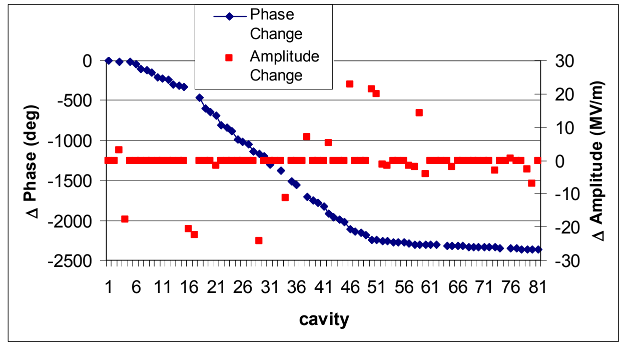

Fig. 5. Phase changes from the original beam based derived setpoints (blue) due to changes in the cavity gradients (red), predicted by the SLACS scaling technique.

SUMMARY

A number of software tools have been developed to support the commissioning and operation of the SNS linac. These tools are critical to fully utilize the flexible nature of the SNS linac. A key component of these tools is use of model based techniques.

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