

DRIFTING BEAM APPLICATION FOR SNS SUPERCONDUCTING CAVITY SETTING*

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Abstract

A software application for tuning superconducting linac cavity has been developed and tested at the Spallation Neutron Source. The application is based on the drifting beam method and the XAL online model. The drifting beam method and the application were proved to be consistent with other cavity tuning method during the SNS commissioning runs. Detail algorithm and data acquisition for the application will be presented.

INTRODUCTION

The Spallation Neutron Source (SNS) superconducting linac (SCL) is capable of accelerating H⁺ ion beam from ~180 MeV to ~1 GeV. The cold linac section contains 81 superconducting RF accelerating cavities. In order to accelerate the beam to a desired energy, the phases for the cavities have to be set correctly. One way for tuning a cavity phase is to send a beam through the cavity with power off and calculate the cavity phase based on the field induced in the cavity. This is called *drifting beam* method. A cavity tuning and measurement application based on the drifting beam algorithm was developed and tested during the initial beam commissioning periods.

DRIFTING BEAM METHOD

One can treat a beam pulse as a series of thin-sliced bunches. When this train of bunches is passing through an RF cavity gap, the particles experience a superimposed field which is a combination of an RF drive, V_{rf} , an induced field V_L from previous bunch passages, and a self-induced field V_{b0} in the accelerating structure [1]:

$$\begin{aligned}
 V &= V_{rf} \cdot \cos \varphi_{rf} - V_L - \frac{1}{2} V_{b0}, \\
 V_L &= V_{b0} \cdot \{ \exp[-T_b (\frac{1}{T_F} + j \cdot d\omega)] + \exp[-2 \cdot T_b (\frac{1}{T_F} + j \cdot d\omega)] + \dots \}, \\
 V_{b0} &= I(\omega) \cdot R_{sh} \cdot \frac{T_b}{T_F},
 \end{aligned} \tag{1}$$

where φ_{rf} is the RF phase, T_b is the beam bunch period, T_F is the filling time for the cavity, R_{sh} is the shunt impedance, I is the image current of the beam bunch in the frequency domain, ω is the angular frequency and $d\omega$ is the cavity detuning. There are six pass-band modes for the SNS 6-cell superconducting accelerating cavity structure. To compute the beam-induced RF signals for the phase and amplitude components of all six pass-band

modes in a cavity, beam signals are assigned to six independent phasors which correspond to these six modes. The resulting beam signal phase and amplitude are obtained from the sum of all these phasors in the six cells as shown in equation 2.

$$V(\varphi) = \sum_{b=1}^N \sum_{m=1}^6 \left[\sum_{c=1}^6 V_{bmc} (\varphi_{bm0} + \omega_m \cdot \Delta t_c + c \cdot \Delta \varphi_m) \right] \cdot e^{\frac{bT_b}{T_F}} \tag{2}$$

where b is the beam bunch number, m is the pass-band mode number and c is the cell number, φ_{bm0} is the initial phase of each mode, ω_m is the angular frequency of each mode, Δt_c is the beam arrival time at each cell, $\Delta \varphi_m$ is the phase advance of each mode. An offline simulation suggests that only two modes, π and $5/6\pi$, are essential for SNS cavities. Therefore, the application only takes into account of these two modes.

DRIFTING BEAM APPLICATION

The drifting beam application is based on the XAL programming framework [2]. The XAL framework provides a common look-and-feel graphical user interface (GUI) for programmers and end users as well as an online model tool [3] for quick physics calculation. The drifting beam algorithm described in the previous section is part of the framework which is available to any XAL-based applications. A screen snapshot of the application is shown in Fig.1.

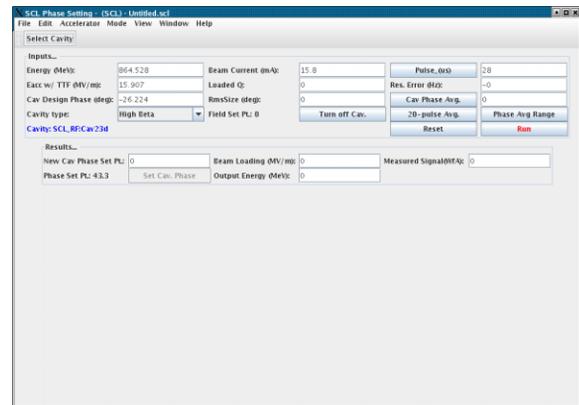


Figure 1: Drifting Beam Application. In this particular snapshot, the last cavity (23d) was chosen.

Application Initialization

For any XAL-based accelerator applications, an XML file representing an accelerator object initializes the application. The XML file provides static information such as cavity design accelerating gradient and phase. A cavity selector button shown in the upper left corner in Fig.1 allows users to select a particular cavity to work

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with. The cavity selector pop-up screen is shown in Fig.2. After a cavity is selected, the XAL online model can then calculate the design beam energy at the entrance of the cavity, and properly set any other required data for drifting beam calculation such as loaded quality factor (Q), transit time factor (TTF) coefficients and their first derivatives.

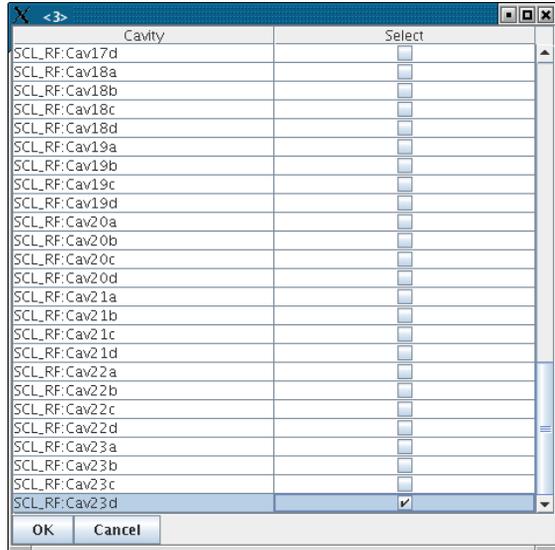


Figure 2: Cavity selector.

Data Collection and Calculation

To carry out the drifting beam calculation, one needs the following online information: longitudinal beam profile, averaged beam intensity over a pulse, beam pulse width, low-level RF (LLRF) waveforms for cavity field and forward power. An upstream beam current monitor (BCM) can give the longitudinal beam intensity distribution and averaged beam current. The application provides a detail screen for displaying the BCM waveform signal and controlling the bunch train slice size as shown in Fig.3. A timing control signal provides the beam pulse width. The LLRF signals can be displayed via another detail screen as shown in Fig. 4.

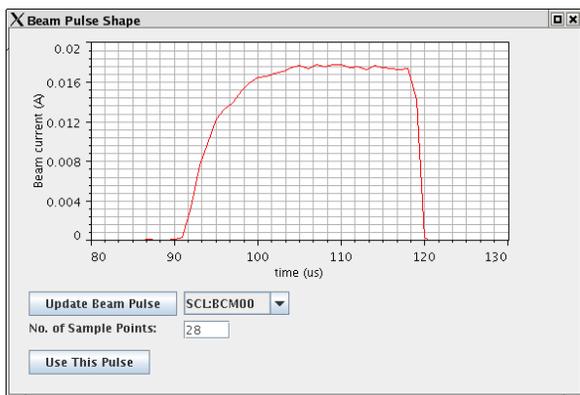


Figure 3: Beam intensity profile from an upstream BCM.

During the SNS commissioning, the cavity field gate is usually more than 1200 μ s while the beam width is much

shorter such as 50 μ s. A range for averaging the cavity phase is automatically determined by the application based on beam width and RF width. Usually the beam is toward the end of the RF gate for stability reason. The averaging range can also be set manually by users.

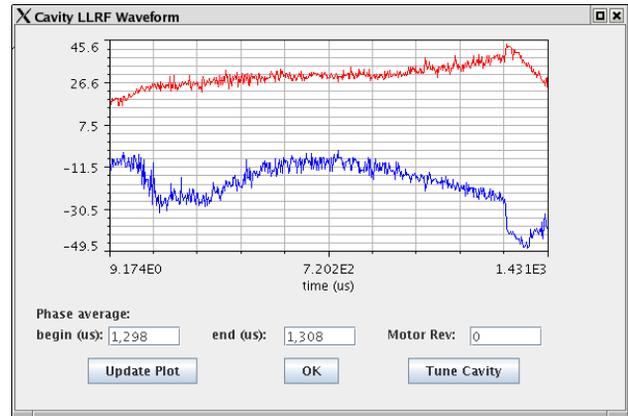


Figure 4: LLRF waveform.

Because SNS is a pulsed machine, the time correlation among various signals is crucial for time-dependent measurements. To ensure all the data coming from the same beam pulse, XAL framework provides a time correlation tool. A set of data is valid only when all individual data timestamps are within a specific time window.

During the commissioning, typically a cavity LLRF runs at higher repetition rate such as 10 Hz for better cavity stability while the beam runs at lower repetition rate such as 1 Hz. Furthermore, the LLRF waveforms are updated at yet another rate because large waveforms can not run faster than 4 Hz for performance and hardware reasons. The data correlation in the application has to take into account of all these factors. Also, to reduce random errors in the data acquisition, an option of averaging the BCM data and LLRF data for 20 beam pulses is provided.

The application also provides a data dump capability for saving BCM and LLRF waveforms into a file for further offline analysis. The saved data can also be used for debugging purpose.

Cavity Control

The application provides limited cavity control functionalities. After initialization, the application first checks if the cavity is powered off. If there is a field larger than 0.5 MV/m, the application will show a warning. The application also has a convenient button to turn the cavity field off. After the beam loading calculation is finished, a suggested cavity phase and other information will show in the result panel. User can then press the “Set Cav. Phase” button to send the new phase setting to the machine.

CONCLUSION

The drifting beam application based on beam loading for the SNS SCL was implemented and tested during the initial beam commissioning. The result agrees with some other tuning techniques [4, 5].

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