A DYNAMIC FEEDBACK MODEL FOR HIGH REPETITION RATE LINAC-DRIVEN FELS*

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Abstract

One of the concepts for the next generation of linac-driven FELs is a CW superconducting linac driving an electron beam with MHz repetition rates. One of the challenges for next generation FELs is improve the stability of the x-ray pulses by improving the shot-to-shot stability of the energy, charge, peak current, and timing jitter of the electron beam. A high repetition rate FEL with a CW linac presents an opportunity to use a variety of broadband feedbacks to stabilize the beam parameters. To understand the performance of such a feedback system, we are developing a dynamic model of the machine with a focus on the longitudinal beam properties. The model is being developed as an extension of the LITrack code and includes the dynamics of the beam-cavity interaction, RF feedback, beam-based feedback, and multibunch effects. In this paper, we present a detailed description of this model.

INTRODUCTION

The tremendous success of the present generation of linac-driven FELs has inspired the design of next generation FEL facilities which push the performance even further. We are investigating the performance of a CW SCRF linac driving an array of FELs with MHz bunch repetition rates. The CW RF and high beam repetition rate allow for the possibility of broadband RF and beam-based feedback to control the electron beam energy, bunch length, arrival time at the FEL and throughout the linac, resulting in a increase in the stability of the output x-ray pulses. We are developing a model to study the performance of the feedback and understand the machine stability. We are also using this model to understand the requirements on the precision required for the RF feedback and beam energy, bunch length, and arrival time monitors.

Typically, an FEL design includes a "jitter" study, where random variations are applied to the beam parameters at the entrance to the linac, such as bunch charge and arrival time, combined with random variations of the amplitude and phase of the accelerating fields in the linac. After passing through one or more dispersive sections (bunch compressors), the resulting variations of the output beam energy, peak current, and arrival time define the stability of the FEL. However, the effect of beam loading on the amplitude and phase of the accelerating fields is typically neglected. For normal conducting linacs, the average current and bunch repetition rate are almost always low enough that beam loading is negligible. However, for superconducting (SC) linacs with high repetition rate beams and moderate average beam currents, the effect can be considerable. For example, even in an ideal accelerating SC module with zero amplitude and phase jitter, variation of the bunch charge and arrival time from the injector will create jitter from variation in the beam loading.

We are developing a model to combine beam loading effects with the dynamics of transport through multiple linac and bunch compressors with the goal to extend the "jitter" studies applied to FEL designs to include dynamic feedback on the measured RF and beam parameters. The model is based on an RF model developed the SNS [1] and the LITrack code [2] for modeling of the beam dynamics.

We are applying this model to the Next Generation Light Source(NGLS) [3], a concept for a soft x-ray FEL driven by a CW superconducting linac with a beam energy of 2.4 GeV. General parameters for NGLS are shown in Table 1. A schematic diagram of NGLS with the concept for the feedback scheme is shown in Fig. 1. Following the high rep-rate, high brightness gun [4], the linac consists of accelerating sections with several dispersive sections. For the purposes of our model, we define a basic accelerator section as a linac (or multiple accelerating sections) followed by a dispersive section (i.e. bunch compressor.) From this building block, we can build up a model of NGLS as well as any other linac.

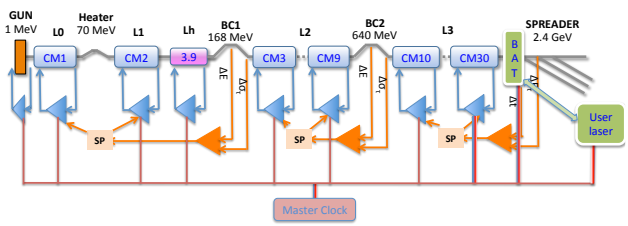

Figure 1: Layout of the NGLS with nested layers of feedback.

FEEDBACK MODEL

A schematic diagram of the model for control of a single linac/bunch compressor module is shown in Fig. 2. Individual bunches are modeled as single macroparticles. The simulation is typically stepped in units of the beam repetition period but it can be clocked with shorter time steps. Beam parameters are input to the RF module and variations of the beam parameters such as bunch charge and timing jitter are given by the injector and not controlled in the present version of the model. Deviations from the

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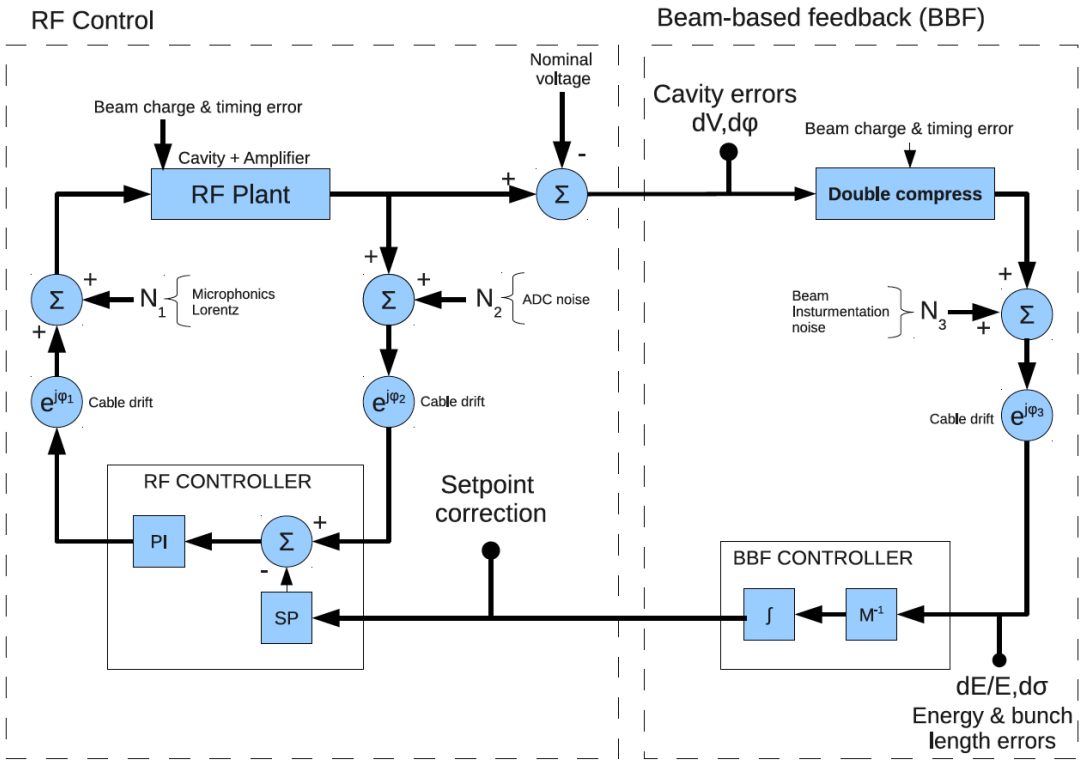

Figure 2: A schematic of the feedback model for each linac/bunch compressor section. Beam parameters are input to the RF module and subsequently transformed in the bunch compressor. Measured beam parameters in the bunch compressor can be fed back to the RF module set points.

Table 1: NGLS Parameters

Parameter		
Energy	2.4	GeV
DC current	0.3	A
bunch charge	0.3	nC
Repetition rate	1	MHz
RF Frequency	1300	MHz
Operating Temperature	1.8	K
$E_{effective}$	16	MV/m
Q_0	2.E+10	
Q_{ext}	2.E+07	
Cavity Length	1	m
R/Q	1036	Ohms
# Cryomodules	27	
Cavities/CM	7	
$\Delta A/A$	0.03	%
Phase stability per Cavity	0.03	Deg

design RF voltage and phase determined in the RF module along with the input beam parameters are passed to the bunch compressor module which transforms the longitudinal beam coordinates, up to second order, through the bunch compressor. Variations of the beam parameters compared to the set point can be measured and used to feedback to the RF module set point. At the current time, we are modeling each linac section as a single RF station, although we have the capability of expanding each linac to multiple RF stations as will be employed for NGLS, allowing us to explore the effect of noise correlations between RF stations.

Details of the RF model are shown in Fig. 3. Features include beam loading, pickup and ADC noise, RF filters, variable delays, klystron response curve, and RF feedback model. This model was originally developed for the SNS RF modeling and has been adapted for NGLS parameters.

The beam dynamics is based on the LITrack code and includes transport of the beam through the bunch compressor to second order. Our work has focussed on transforming deviations of the energy and bunch length from nominal at the bunch compressor into corrections for the set points of the amplitude and phase of the preceding linac sections. For each configuration of the linac, we determine a sensitivity matrix which provides linear variations of the measured parameters with respect to amplitudes and phases in the linac sections as shown in Fig. 4. Inversion of this matrix provides the correction values to the linac set points. Noise can be added to the energy and bunch length measurements and the gain and bandwidth to the set point correction can be varied.

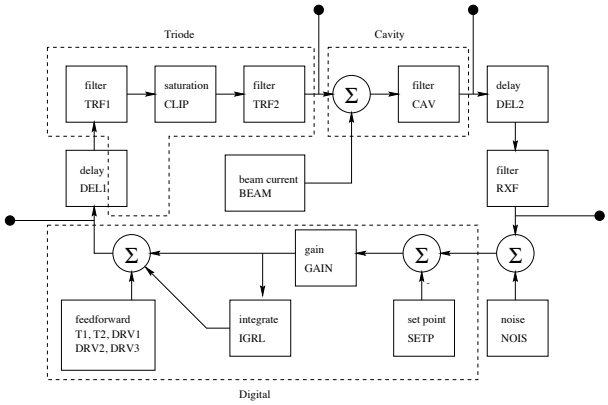

Figure 3: Detailed RF model.

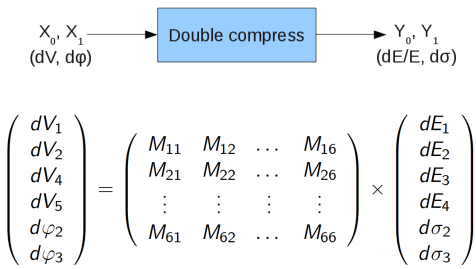

Figure 4: Response matrix transforming variations of the beam parameters to RF voltage and phase corrections.

INITIAL RESULTS

By the time of this conference, we only have been able to produce initial results using the combined features of RF and beam-based feedback. One example illustrating the beam-based feedback is shown in Fig. 5. The top plot shows energy drift in L1 (linac 1 from Fig. 1) resulting from a drift in cable. The RF FB is on and the BB FB is off. This is followed by a step voltage change in the linac. The second and third plot shows the linac voltage and phase with BB FB on. The fourth shows the resulting energy drift for various gain values of the BB FB.

SUMMARY

We have developed a model to study the beam jitter and stability of a series of linacs and bunch compressors. The model includes beam loading, beam dynamics transport in the bunch compressor to second order, RF and beam-based feedback. The model is being applied to the NGLS, a proposed CW SC linac driving an array of FELs. Only initial results are available at the time of this conference but are promising. Over the next year, we plan to use this model as a tool to specify the stability of critical machine diagnostics and stability requirements from the injector.

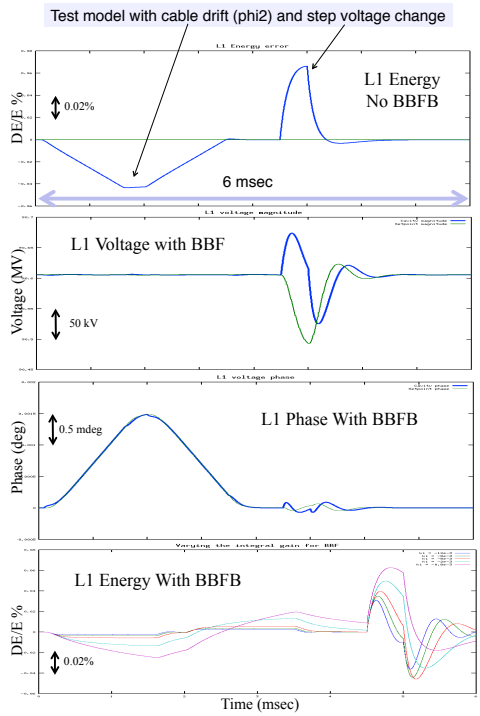

Figure 5: Initial results from the model for a single linac/bunch compressor module. a) Energy drift from RF cable drift (phi2) and a step voltage change. b) Effect of beam-based FB on voltage set point. c) effect of beam-based FB on phase set point. d) Energy drift with RF and beam-based FB at different gains.

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