ENERGY FEED FORWARD AT THE SLC*

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Abstract

The energy of the SLC scavenger electron beam used to produce positrons for the next cycle and the average energy of the electron and positron bunches collided in the linear collider must be stable to maintain efficient machine operating conditions. Energies are stabilized using a newly installed hardware-based feed forward[1] system. The three bunches are stored and cooled in the damping rings, and co-accelerated in a single machine cycle. Prior to extraction of the stored bunches, the energy gain of the accelerator is set by re-phasing of klystrons to correct for anticipated beam loading effects. We will discuss the hardware associated with determining the intensities and the appropriate energy corrections to compensate for variations in energy due to beam loading effects. We will discuss machine tuning procedures, diagnostics, and operational experience.

I. INTRODUCTION

When operated in its design 3-bunch mode, the positron source for the Stanford Linear Collider[2] (SLC) is sensitive to variations in bunch intensities of not only the scavenger electron bunch (used to produce next cycle's positrons) but of the preceding luminosity positron and electron bunches as well.

There are 3 bunches, each with its own beam loading function, which contribute to the depletion of the available rf fields in the accelerator. The scavenger bunch (bunch number 3) will arrive at the extraction transport line "off energy" if there is any change in the charge of any of the 3 bunches with respect to their nominal values

This problem is exasperated following a machine protection cycle, when there are no stored positrons and the full intensity beam which is used to create positrons does not experience the (missing) positrons' loading.

Dedicated electronics has been built to allow the sampling of the stored beam intensity several milliseconds prior to extraction from the damping rings; the intensities of the three bunches are used to predict the energy error of the next scavenger electron bunch. Two kilometers remote from the damping rings, supporting electronics has been installed which takes the predicted error, and corrects the energy profile of the accelerator just upstream of the extraction point in the linac.

Two sectors (out of 31 total) are used to adjust the energy of the extracted beam. Low power phase shifters are set with coefficients derived from the slower feedback[3,4] system to "kink" the phase of the two sectors of klystrons.

II. ELECTRONICS

There are 4 discrete types of electronics used in the feed forward system: An intensity sampler, a sampling module which predicts the energy error, a computing module which calculates appropriate phase settings, and some rf hardware to affect the correction.

A. Intensity Sampler

In the SLC, the beam in the damping rings is delivered to the linac with very little loss. Sampling of the

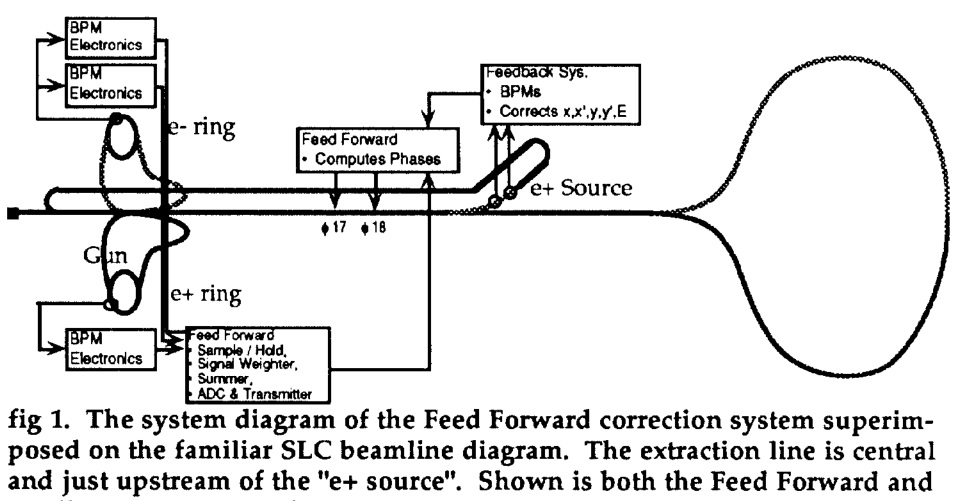

fig 1. The system diagram of the Feed Forward correction system superimposed on the familiar SLC beamline diagram. The extraction line is central and just upstream of the "e+ source". Shown is both the Feed Forward and Feedback components for this system.

* Supported by the Department of Energy, Contract DE-AC03-76SF00515

beam position and intensity is done for steering and diagnostics using a specialized beam position monitor (BPM) electronics package[5]. For this feed forward application, the standard BPM module is used with a stripline position monitor to determine only the intensity of the stored beam.

B. *Sampling Module*

The beam loading of a nominal 3-5 10^{10} particles in each of the three bunches on the scavenger electrons is different due primarily to the following effects:

- Positrons: The fundamental loading of this bunch is fractionally "washed-out" by the timing of the third bunch due to the the 130 nS bunch timing separation and the 825 nS accelerator fill time .
- Electrons: As for the positrons, there is a wash-out effect with strength of only 60 nS.
- Scavenger electrons: The median energy of this bunch is stabilized, therefore a) only half the charge is considered, and b) since this bunch experiences its own self-loading in the accelerator, the fundamental and all higher modes contribute to self loading.

There is a CAMAC sampling module[6] which interfaces to both the SLC timing system and the BPM electronics. Interfacing to the other modules, a set of gates are provided to the beam position electronics and signals are available for monitoring and diagnostics. Inputs to the module are timing signals from the timing system and the "Sum" signal from the BPM electronics. Internally there are appropriate gain and offset levels. These signals are processed as follows:

1 Offset (or pedestal) value is subtracted independently for each channel,

2 Gain Coefficient is applied to each channel. This data is summed as follows and is sampled with a GADC,

3 Three outputs are summed, with an additional offset term,

4 Result is sampled and digitized. Sampled values are monitored by GADC and a normal ADC, and digital format is sent as differential data to the feed forward computer module. Data transmission is via a 32 kilobaud differential serial link.

Results from this module are sent to the computing module (below) located near the positron extraction line 2 km distant.

C. *Computing Module*

The resultant action from the predicted energy offset is the re-phasing of two sectors of high power klystrons. Hardware phase shifters allow the control of these rf devices, with the two sectors (acceleration 2 GeV each) to be symmetrically mis-phased, or "kinked". This can allow quick correction for energy control without the introduction of significant changes in energy spread.

Corrections from feed forward are complicated by the simultaneous corrections by slower "fast" energy feedback systems. The feed forward corrects for anticipated errors due to accelerator beam loading effects, while the feedback system repairs errors due to anomalous drifting and changes of accelerator rf, transport components, and any errors introduced by the feed forward system. Communications between the two systems is achieved by locating the phase computer CAMAC module in a feedback controlled crate, and having the feedback process continually adjust the feed forward coefficients to the newest optimum value.

The computing module is a CAMAC module[7] which receives the digital loading correction data from the sampler module, and applies pre-programmed constant, linear and quadratic coefficients to compute new phase shifter settings.

For simplification from the control software standpoint, both this module and the sampler module are designed to identically replicate the SLC standard DAC module used by the SLC, allowing standard software support to be used in the setting and updating of the coefficients. All "DAC" values, whether used internally as digital multipliers or analog offsets, are available from the front panel and read by a multi-channel ADC, again to allow the control system the standard feature of readback of these virtual components.

D. *Associated RF Hardware*

The phase setting determined from the computing module is sent as an analog voltage to two rf phase shifters[8]. These low power phase shifters consist of a pair of varactor diodes and a 3 dB splitter. Installed just prior to the rf multiplier, they allow a ±180° phase control of a sector of klystrons each. Similar hardware is used by a fast feedback process to stabilize the linac energy (see ref. 3).

III. OPERATIONAL EXPERIENCE

Recent operation of the accelerator has allowed for a brief pre-conference commissioning effort on this new system. Accelerator physics programs have verified that:

- The beam loading intensity dependence is near expected theoretical values.
- The installed hardware has been commissioned, passing expected performance tests.
- The energy deviations of a single bunch with deliberately introduced intensity variations can be reduced.

A. *Beam Loading Effects:*

The loading of the accelerator was measured using the extraction transport line as a spectrometer while the intensity of the scavenger bunch was statically varied (see fig. 2). The results are in agreement with expectation (*c.f.*: Ref. 1), with resulting energy dependence of -159 MeV / 10**10 particles. Static tests varying the intensity of the

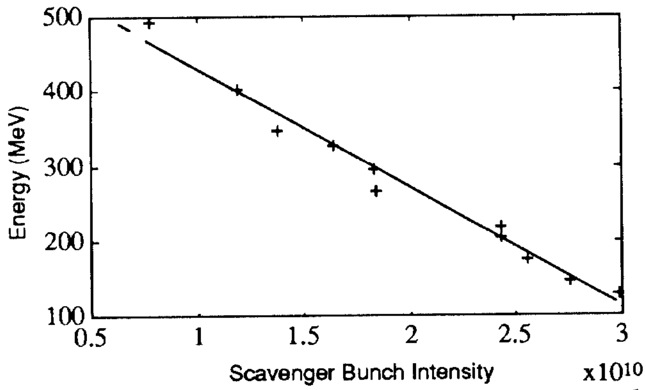

fig. 2. The energy of the scavenger bunch correlated against intensity measured in the Damping Ring. Slope of −159 MeV/1010 electrons is in agreement with the expectation value of −172.**

positron current showed similar agreement with expectations. Definitive measurements of the beam energy on a pulse-to-pulse basis is difficult, since the accelerator's extraction line is not equipped with sufficient BPMs that can be read simultaneously (un-multiplexed) to cleanly separate launch errors in x, x' from $\Delta E/E$ errors.

B. Hardware

Initial results suggest that the hardware is operating as intended. While there is insufficient operational experience to report on the machine tuning procedures, it is clear that the calibration of the sampling system (the dependence of energy loading on beam intensities) will require some attention.

Missing from the design is any way to separate the calibration of the detectors from the assignment of beam loading coefficients. The authors intend to rectifying the situation by the addition of a set of three gain stages which will allow the operations support personnel to independently verify that the module reports the same beam current as the machine diagnostics report, and will allow the separate assignment of beam loading weights.

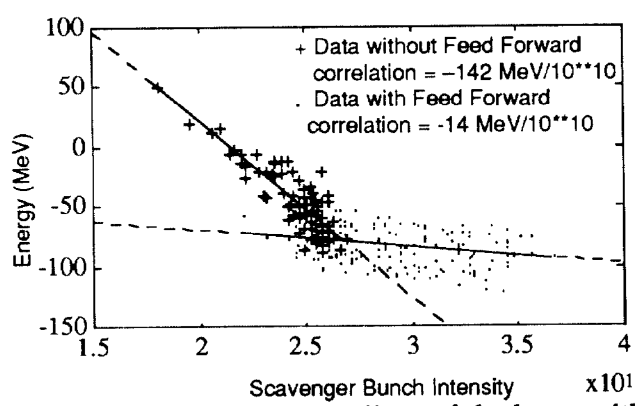

fig. 3. Shown is the energy jitter of the beam with and without feed forward. The energy of the beam can be estimated on a pulse-to-pulse basis using sampled data and the known dispersion value for the BPM.

C. Commissioning Results:

The Energy Feed Forward system has undergone initial commissioning in early May 1991. For some of these tests, the machine was deliberately mis-tuned to generate larger intensity fluctuations, and therefore larger intensity-dependent energy variations from the scavenger beam's self loading. BPM analysis allows a rough determination of the energy jitter through the knowledge of the system's dispersion of η = -26 cm and energy of 35 GeV. Shown in fig. 3 is the sampled data from consecutive machine pulses in the SLC. Superimposed on this plot is the energy jitter from the machine both with and without the feed forward system operational.

Initially, the energy intensity dependence as observed was -140 MeV for every 10**10 scavenger electrons; feed forward reduced this by a factor of 10.

Further commissioning will require additional attention paid to the specific intensity dependence the energy has to each of the three bunch currents. Additionally, further verification of the stability and performance of the intensity detectors is required.

IV. ACKNOWLEDGMENTS

The authors would like to thank Artem Kulikov for the suggestion to stabilize scavenger energy by a energy feed forward system based on stored charges.

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