POSITION, ANGLE AND ENERGY STABILIZATION FOR THE SLC POSITRON TARGET AND ARCs*

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Abstract

Slow feedback has been developed to control the position, angle, and energy of the three SLC bunches in the linac at the South Arc, North Arc, and positron target respectively. A set of computer controlled feedback loops calculate the parameters of each bunch from beam position monitor data in the appropriate extraction line. The angles and positions are corrected by orthogonal sets of steering dipoles. The energy is corrected by adjusting the phase of two upstream sectors of the linac. This paper discusses the data acquisition and algorithms.

Introduction

The FEEDBACK process[1] is responsible for stabilizing slowly changing systems such as Kicker Timing, Main Drive Line length compensation, automated Klystron Replacement, and Beam Stabilization. This is achieved by the creation of a number of feedback loops which measure and stabilize a specific machine parameter, often using the beam as the measurement device.

These sets of feedback loops are clustered into a number of logical Groups of loops, where each Group contains the loops for a specific Region of the machine, and each loop stabilizes a specific measurable parameter.

The Energy Feedback loop driver supports those loops which utilize the beam as the measurement tool, using BPM's and other types of beam analyzers to monitor some quality of a conventional beam which is to be minimized or stabilized. The Beam parameters which the feedback process is controlling are[2] :

- Stabilization of Energy error (E).
- Minimization of Energy spread (σE).
- Stabilization of Two bunch energy difference (ΔE).
- Stabilization of Beam Trajectories, Position and Angle errors (X, Y, X', Y').

The Loops

Geographically, these feedback loops are distributed in clusters in the Regions of the Linac which have parameters which must be stabilized. Currently, beam related feedback loops have been defined in eight regions. The regions are shown in Figure 1, and are listed below:

- Linac into Damping Rings – Loops in these regions measure and stabilize the energy and trajectory, and minimize the energy spread of the beam entering the damping rings.
- Damping Rings to Linac – Loops in these regions measure and stabilize the trajectory extracted beam from the damping rings on re-injection into the Linac.
- Extracted Electrons to Positron Target – Loops in this region measure the energy, position, and trajectory of the last bunch of electrons extracted from the linac. Trajectory and position corrections are applied, and the beam lattice is rescaled to track the energy drifts.
- Beam Switchyard – Loops in these regions measure and stabilize the energy and trajectory, and minimize the energy spread of the electrons and positrons at the end of the Linac.
- Arc Regions – Loops in these regions measure and stabilize the trajectory of the beam at the start of the alternating gradient magnets in both of the SLC Arcs.

Each individual loop is designed to stabilize or minimize a single measurable beam parameter. Most regions have several loops defined, where each loop is designed to have a minimal impact on the stability of all other loops. The individual loops have unique names which are described in the database, and operational parameters for each loop are stored in the database, as well as the current state of each loop.

DATA ACQUISITION

The acquisition of Beam Position Monitor (BPM) data is limited by the rate of the beam under study, and by the number of displays running for the machine operators. The feedback code is structured to make the most efficient use of the acquired data, reducing the load on this limited resource. For each region, or group of loops, there is typically one BPM data definition and calibration file, as well as an associated injection region.

For each injection region, an averaged BPM reading (typically three samples) is acquired using standard BPM software support[3] the measurable beam parameters are calculated from the raw data. Only if corrective action is taken which affects the validity of the data set, is the data re-acquired for a subsequent loop in any region.

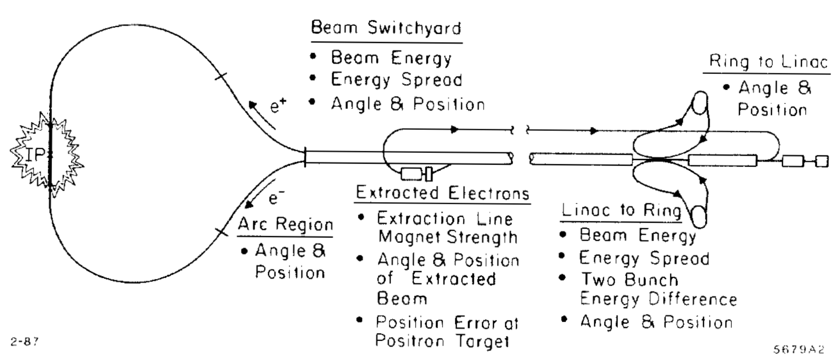

Fig. 1. Beam Stabilization loops in the SLC. The loops are clustered in a small number of regions along the accelerator and into the Arcs.

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The model driven injection region analysis routines[4] calculate the energy and trajectory of the beam at a given point. The routines use a configuration file which defines the point of analysis, the desired beam trajectory, and some magnetic elements. With the "*golden*" orbit through each beam transport line defined, the routines use the recently acquired BPM data, and machine transport parameters available from the database, to analyze the error in the beam's path.

Loop Specific controls

All of the loops use the injection software to calculate the relevant parameters from current BPM readings. The major differences in the individual loops is that each loop uses a different set of control devices to compensate for the observed signal. Additionally, the individual loops often compensate for their actions by using a secondary control device. This Feed Forward is necessary to make the loops approximately orthogonal.

ENERGY STABILIZATION LOOPS (E)

The energy of the beam is controlled either a) by changing the RF output of a klystron[5], b) by perturbing the phase of two sectors of klystrons, resulting in a change of their total energy gain, or c) by tracking the energy changes by adjusting the bend magnets for the extracted electrons into the positron source.

The energy controls for the two damping rings use vernier klystron stations in sectors 0 and 1 to control the energy delivered to the appropriate beam. Since the electrons share the sector 1 control with the positrons, an increase in the positron energy gain through sector 1 must be compensated by a change in the electron energy gain using an "electrons only" station in sector 0.

Energy control at the end of the Linac uses the phase settings of two sectors of klystrons. The phase values are kinked to reduce the total energy gain, while holding the longitudinal energy contribution invariant.

Changes in the energy of the extracted electrons into the positron source are compensated by rescaling the extraction line lattice.

ENERGY SPREAD MINIMIZATION LOOPS (σE)

The energy spread of the beam is controlled by changing the phase of the RF with respect to the beam, resulting in a different energy gain of the head with respect to the tail. Control algorithms for these loops are quite different, since this parameter can only be minimized.

The control for each of the energy spread loops is the change of the position of the beam on the RF waveform. By introducing a phase error, the longitudinal energy dependence is affected. This can result in rather substantial changes in the net energy gain by the beam, which must be compensated by appropriate Feed Forward.

ENERGY DIFFERENCE STABILIZATION LOOP (ΔE)

The energy difference of the two electron bunches is controlled by changing the timing of the SLED cavity discharge. The first bunch passes through the RF accelerator section before it is completely filled, allowing the second bunch a slightly higher unloaded energy gain. The change in SLED timing introduces an unloaded energy difference comparable to the beam loading. This may result in rather large changes in the total energy gain of the system, which must be compensated.

BEAM TRAJECTORIES, POSITION AND ANGLE STABILIZATION LOOPS (X, Y, X', Y')

The loops stabilizing beam position and angle offsets in X or Y have as primary control elements a set of two or four steering dipole magnets. (Four in regions where there are both positron and electron bunches, two otherwise). The loops for a particular location are orthogonal, *e.g.*, the loop that corrects X should not affect X', Y, or Y'. Trajectory stabilization loops for horizontal and vertical position and angle exist for injection into the North and South Damping Rings, from the Rings to the Linac, and into the North and South Arcs. There are also loops to stabilize horizontal and vertical position on the positron target.

Beam Stabilization Algorithms

At scheduled intervals, the FEEDBACK process may call upon the energy feedback driver to service any loops which require servicing. The driver loops through all regions, and through all loops in each region, skipping regions and loops which are not scheduled. If any specific loop requires servicing, then the appropriate data acquisition routines are called (if necessary), and a correction may be applied. An overall flow diagram is presented in Figure 2.

The various loops discussed have different data acquisition and control algorithms. The general case is presented, followed by a more detailed description of the algorithm used for energy spread minimization.

GENERAL LOOP CONTROL

Most of the loops are supported with the simple *feed-on-errors* method, or the discrete *"I"* (Integral) control method. With this method, the new value of the control parameter is equal to the starting value, minus the sum of all previous signal errors multiplied by a gain factor. Equivalently, the new value is equal to the current value minus the signal error multiplied by a gain factor. The two equations are given below. The latter form of the equation is used by most loop drivers.

$$\text{Control}_n = \text{Control}_0 - \sum_{m=1}^{n} \text{Gain} * (\text{Signal}_m - \text{Setpoint})$$

$$\text{Control}_n = \text{Control}_{n-1} - \text{Gain} * (\text{Signal}_n - \text{Setpoint})$$

This implementation has the following discrete steps:

1. Acquire the data. This involves an averaged BPM reading, followed by analysis to extract the injection parameters using the model of the machine. If the data set for this loop is still valid following the execution of another loop in the current region, the data is reused.
2. Process the data from the analysis results. This can be as easy as multiplying the fractional error by the beam energy. This is saved in the database as the loop's signal.
3. Test for tolerances. The database for each loop specifies the limits within which the loop is considered stable, (*i.e.*, the capture range of the loop). The current signal is compared with the setpoint using the tolerances and the limits. If the signal either is within the tolerances or exceeds the limits, no correction is attempted.
4. Calculate the correction. The database gain factor is applied, and a loop correction is calculated.
5. Compute the response. Loop specific drivers apply the correction to the primary and secondary control device(s), and compute the new database command attribute, and the natural control limits of control available to the affected devices.
6. Test the predicted response against both the database limits and the natural limits of the controlled devices. If the command exceeds either set of limits, an error is generated, and no further action is attempted.

7. Execute the response.
8. Mark the acquired Beam data for loops in this group as no longer valid, if necessary.
9. Log the response.

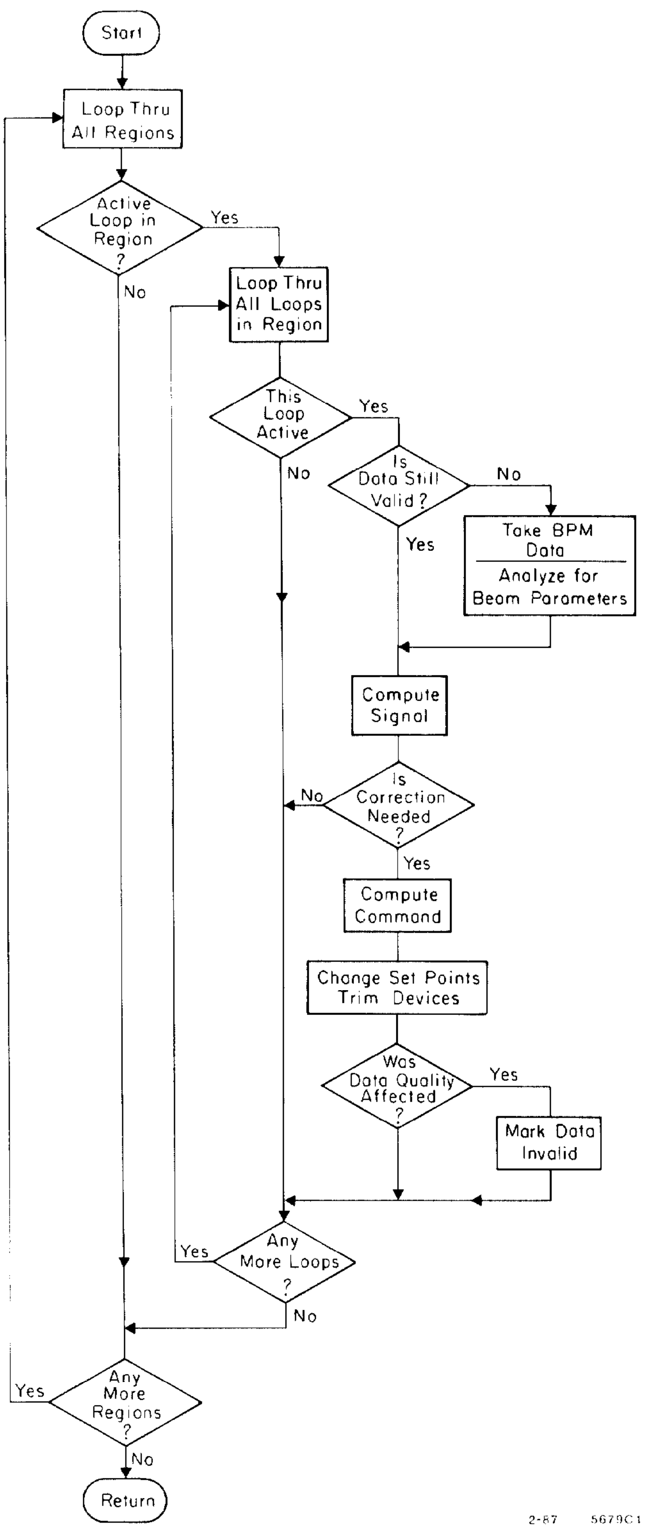

Fig. 2. Block diagram showing the overall loop structure of beam stabilization feedback loops.

Energy spread algorithms

The goals of the energy spread feedback loops are to minimize the observed energy spread of the beam rather than to stabilize the system at some target value. This is a non-linear problem which is implemented with a systematic search algorithm.

The minimum energy spread is not at a zero actual width, but rather at the point where the horizontal projection of the beam profile is a minimum. For the non-intercepting quadrupole moment monitors[6] this is the point of the absolute minimum in the measured beam size signal. The minimum is found by changing the phase (and the energy gain) of one or more upstream LINAC sectors.

The loop's algorithm separates the tasks of determining an out-of-tolerance system from that of finding the optimum operating conditions:

- At a relatively fast rate (one sample per Minute), the energy spread data is acquired. The last few data points are averaged, and the results saved as the current signal.
- At a relatively slow rate (once per 10 minutes), the current signal is compared with the setpoint. If the signal either is within the tolerances or exceeds the limits, no minimization is attempted.

If an update is indeed required, then the following search is performed:

1. The phase of the upstream linac is stepped positive and then negative by a standard phase quantum. At each step, an energy vernier is used to compensate for both the anticipated energy change and the current measured energy error.
2. The data-set is run through a standard least squares analysis to fit a parabola to the measured energy spread as a function of phase.
3. The minimum of the energy spread parabola is required to be within both the database limits specified for the command variable, and the actual range of the data acquisition.
4. The response is tested, executed, and logged as described above.

Conclusions

The slow feedback has been commissioned in a number of regions in the SLC. With appropriate tests for data quality, automatic feedback loops have significantly improved the stability of the accelerator.

Acknowledgments

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