Luminosity Optimization Feedback in the SLC

L. Hendrickson, S. Bes, P. Grossberg, D. McCormick, N. Phinney, P. Raimondi, M. Ross
Stanford Linear Accelerator Center, Stanford University
Stanford, California 94309

Abstract

The luminosity optimization at the SLC has been limited by the precision with which one can measure the micron size beams at the Interaction Point. Ten independent tuning parameters must be adjusted. An automated application has been used to scan each parameter over a significant range and set the minimum beam size as measured with a beam-beam deflection scan. Measurement errors limited the accuracy of this procedure and degraded the resulting luminosity.

A new luminosity optimization feedback system has been developed using novel dithering techniques to maximize the luminosity with respect to the 10 parameters, which are adjusted one at a time. Control devices are perturbed around nominal setpoints, while the averaged readout of a digitized luminosity monitor measurement is accumulated for each setting. Results are averaged over many pulses to achieve high precision and then fitted to determine the optimal setting. The dithering itself causes a small loss in luminosity, but the improved optimization is expected to significantly enhance the performance of the SLC. Commissioning results are reported.

1 Introduction

As the SLC beams approach the collision point, they are focused through a series of quadrupole and sextupole magnets. For each beam, five orthogonal combinations of magnets are adjusted to optimize beam size at the interaction point. Prior to 1997, optimization was performed periodically at operator request by a semi-automated procedure which scans the devices through a series of values while measuring the resulting beam size. A parabolic fit to beam size squared as a function of setting determines the optimal device values but operator judgement is required to decide whether to implement the proposed correction. Figure 1 shows a typical scan. This procedure has several shortcomings which have become more evident as upgrades to the SLC optics reduced the minimum beam size achievable. One problem is that on the extreme ends of the scan, the error in the beam size measurement is large, degrading the scan resolution. Because the optimization is dependent on human intervention, the machine was not always kept in a fully optimized state; typically corrections were applied only every 8 hours. The full set of scans could take up to an hour to complete with the machine necessarily mistuned during much of that time. Since the scans are relatively slow, the results may also be adversely affected in unrelated beam changes during the scan. Inaccuracies of the IP tuning are estimated to have been responsible for about 20-40% average luminosity loss over the 1995 and 1996 SLC runs [1]. An automated feedback was designed to improve the resolution of the measurements, and to maintain maximum luminosity.

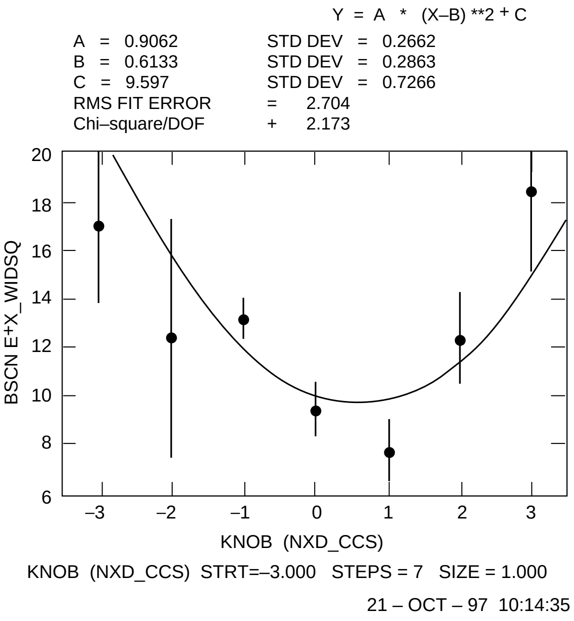

Figure. 1. Optimization scan method. A linear combination of magnets is scanned. At each point in the plot, the beam width is measured by steering one beam across the other and fitting the resulting deflection angles.

2 Dithering feedback

Dithering techniques were developed as an alternative to the scan method. They are useful where measurements respond parabolically with actuator movement. In these cases, given a single raw measurement, there is not enough information for a feedback to tell which way to move the actuator, because it may be on either side of the curve. One way to obtain this information is to move the actuator and observe the measurement change. Dithering involves perturbing the actuator by a small amount above and below its nominal setting while taking synchronous beam measurements. A digitized

---

[*] Work supported by the Department of Energy, contract DE-AC03-76SF00515

analog readout which is proportional to luminosity is read on each accelerator pulse, at 120 Hz. As the feedback software moves the devices, it accumulates average luminosity readouts for each of the three settings (nominal, above and below). After averaging many pulses, the software calculates the offset of the parabola, and moves to the newly calculated optimal setting.

The dithering method was first proposed and developed in 1993 [2]. A system was designed to optimize the energy spread of the SLC beams, but was discontinued due to operational complications. The design for the current luminosity optimization feedback is built upon the previous implementation, but upgraded to handle slower devices. The earlier system used only two dithering steps (up and down) and required the use of quickly responding devices; it included assumptions about the slope of the parabola being optimized. The current system, with three dither settings, makes no modeling assumptions.

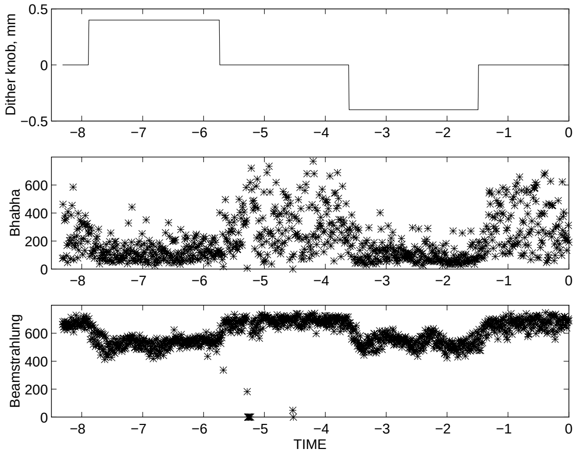

Figure. 2. Response of digitized luminosity monitors during dithering. The dither pattern is CENTER, UP, CENTER, DOWN. Originally a radiated bhabha counter was used as the monitor, but at higher luminosity, the beamstrahlung monitor provides a more stable result.

3 Software design

The software design for the optimization system is built upon existing feedback systems. The SLC fast feedback is capable of measuring and controlling the beam at the full beam rate of 120 Hz [3]; it was upgraded to perform the dithering functions described above. To keep the design simple, the fast feedback system is not required to handle the interaction between multiple tuning parameters. Ten feedback loops were created and commissioned, turning on only one at a time. The system is database-driven, so that only database work is required to support new loops of an existing type.

In order to eliminate interaction between the optimization parameters, a scheduler is used. The user configures the frequency for performing each optimization, and only one is on at a time. The user may enable or disable individual loops. By turning off the automatic scheduling, the user regains manual control over the optimization. At present, the scheduler runs at a 15 second interval, turning on or off the individual feedback loops according to user determined criteria.

4 Timing and luminosity losses

The dithering technique inherently requires a luminosity loss in order to perform the measurement. Therefore the system parameters are tuned to provide the most optimal tuning with the least disruption and luminosity loss. Several parameters are provided for user control, and the goal of maximum total luminosity does not necessarily result in the most precise optimization. For example, by increasing the dither size, the measurement becomes more accurate but also more invasive. Increasing the number of averaged pulses for each measurement also improves the resolution; but the tradeoff is a longer dithering time and sensitivity to unrelated beam movements. The optimization devices are slow to repond, and take about a quarter of a second to achieve a requested change. On each new dither setting, the feedback rejects a specified number of pulses while the magnets settle. The user can also control the number of good pulses on which the feedback stays at each dither value before moving to the next setting. In addition, filtering parameters allow the user to reject data on anomalous pulses. Tolerances for each optimization parameter enable the scheduler to determine whether to iterate or to move on to the next loop. Finally, a timer for each parameter is provided, so that slowly changing parameters may be optimized less frequently if desired.

As presently configured, each optimization parameter is controlled on a 40 minute timer. For each dither step, the devices settle for 30 pulses before the feedback collects 200 good pulses of data. The number of good pulses averaged for an optimization measurement is 3200, which takes about 38 seconds. While the dithering is on, 70% of the pulses are used for results, 11% are for magnet settle time and 19% are filtered or rejected. When a measurement is within the user specified tolerance, the scheduler turns it off and moves on to the next loop. If necessary, the feedback loop is left on for up to 5 minutes in order to converge. Each feedback loop executes for 105 seconds on average and typically, some dithering is active 44% of the time.

The luminosity loss due to dithering is calculated using the configured dither size and the parabolic parameters from the scan method. The average dither size results in 16% luminosity loss, but the nominal dither value is used half of the time, and the dithering is running 44% of the time. This results in a luminosity loss due to dithering of just over 3% as of October, 1997. Earlier in the commissioning, more conservative system parameters were used, resulting in a larger luminosity loss of about 6%.

5 Commissioning experience

Several weeks were required to complete commissioning of the optimization system, as various operational challenges were encountered and overcome. An essential element of the optimization system is a monitor which reliably reads a maximum value where the luminosity is a maximum. Originally, counters which detect radiated bhabha events were used for optimization; one of these monitors seemed to have a good response, but may have had acceptance problems which caused the peak signal to occur at other than the optimal point. This would have resulted in the feedback maintaining a suboptimal luminosity! Furthermore, at higher luminosities, backgrounds and other systematics in these monitors made them unreliable. Finally the beamstrahlung monitors, which measure the energy of photons radiated during the beam-beam interaction were found to provide a stable response with minimal noise. Figure 2 shows the dithering response for both types of monitors. This only emphasizes the importance of finding a reliable luminosity signal free of contamination.

During testing, each of the ten optimization variables was deliberately mistuned to study the correctness and convergence of the feedback response. For small changes, the feedback converges quickly with few iterations. For mistuning larger than the dither size, the parabolic fit is poorly constrained and the feedback typically overestimates the correction needed. To prevent overshooting, the maximum allowed movement after a single measurement is required to be less than dither size.

By averaging a large number of pulses, the optimization feedback is able to achieve much better resolution on each parameters than with the previous scan technique. Figure 3 shows the improved resolution of the feedback optimization measurements, compared with results from the scans. The measurement resolution is improved by about a factor of 5.

6 Conclusions and future plans

A novel dithering feedback has been implemented to optimize the beams at the SLC interaction point. Ten parameters are tuned including horizontal and vertical focus, dispersion, and coupling. With the new feedback the measurement resolution is improved by about a factor of 5. Over long periods, the feedbacks are able to maintain the optimization parameters within much tighter tolerances than previously.

The new optimization feedback has many other operational benefits. Because it is completely automatic, recovery from interruptions is faster and more reliable. The feedback also keeps these final parameters tuned for peak performance without relying on the skill or judgement of particular operators or physicists. In addition, previous techniques absorbed a large fraction of the efforts of an operator who is now freed to concentrate on analysis and tuning of other parts of the machine.

One measure of the success or failure of a feedback system is whether the operators choose to turn it off: after the commissioning phase was completed, the luminosity feedbacks have remained on, with few complaints. Since the introduction of the system, the SLC has been able to achieve and maintain record-high luminosity, and the feedback system is credited with contributing to this success.

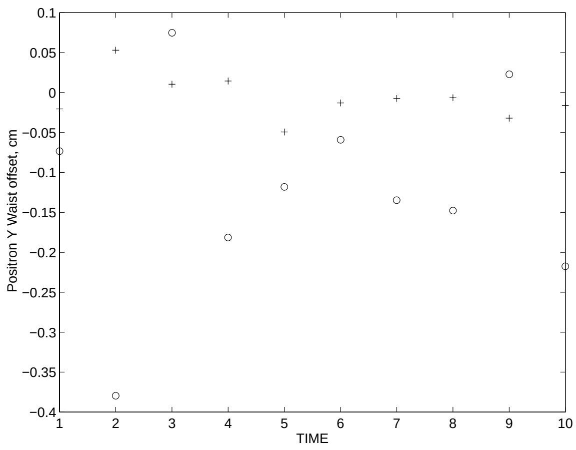

Figure. 3. Resolution of optimization measurements for scan results (o) compared to feedback measurements (+). With the feedback off, ten optimization scans were performed (o) and corrections were not implemented. Then the feedback system was used to take ten comparable measurements (+).

In the future, the optimization system may be extended to control beam orbit bumps in the SLC linac, which are currently controlled via operator scans. Additionally, the system may be used to maximize luminosity in the PEPII B Factory.

Acknowledgements

The optimization system has benefitted from the contributions of many operators and physicists as well as hardware and software engineers. In particular, Paul Emma and Frank Zimmerman were instrumental in analyzing the potential luminosity improvements and initiating development of the system.

References

[1] P. Emma et al., Limitations of Interaction-Point Spot-Size Tuning at the SLC, In Proc. of the IEEE Part. Acce. Conf., SLAC, May 1997. SLAC-PUB-7509.

[2] M.C.Ross, L. Hendrickson, T. Himel and E. Miller, Precise System Stabilization at SLC using Dither Techniques, Proc. of the IEEE Part. Acce. Conf., SLAC, May 1993. SLAC-PUB-6102.

[3] L. Hendrickson et al., Generalized Fast Feedback System in the SLC, in Proc. of ICALEPCS'91, SLAC, November 1991. SLAC-PUB-5683.