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Beam-based Feedback Testing and Simulations for the SLC Linac

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Beam-based Feedback Testing and Simulations for the SLC Linac[*]

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Abstract

Beam-based feedback systems were a key element in the successful operation of the Stanford Linear Collider (SLC) but the performance was not optimal. Some limitations were incomplete communication between the feedback loops, slow correctors, and constraints on the placement of feedback devices. Recent beam experiments and simulations have improved our understanding of feedback performance characteristics, and increased our confidence in designing feedback systems for the Next Linear Collider (NLC).

1 INTRODUCTION

In a linear collider, the beam trajectory must be carefully maintained through the center of the quadrupoles and structures to avoid emittance dilution. For the SLC, a sequence of orbit feedback systems was used along the two-mile linac. To avoid having multiple loops respond to an incoming disturbance, each system was designed to communicate information to its downstream neighbor. However, in the presence of strong wakefields, the beam transport depends on the origin of the perturbation and a more complex interconnection is required where each feedback receives information from all upstream loops.

A generalized beam-based feedback system [1] was implemented for the SLC starting in 1990. The linac had seven orbit feedback loops which used beam position monitor (BPM) measurements and dipole correctors. Initially the feedbacks did not communicate with each other. In order to reduce overcorrection, the gains were lowered so that each loop implemented only a fraction of the calculated correction. In 1994, a "cascade" system was added to pass beam information from each loop to the next downstream feedback. At low intensity, this allowed the linac feedback to run at full gain.

As the beam intensity increased, wakefield effects became more significant and the feedback no longer performed optimally. More feedback loops were inserted to improve the orbit correction and eventually the linac had ten loops running at a variety of rates, not all of which were connected by the cascade system. Due to bandwidth limitations, most loops operated at a subset of the 120 Hz beam rate. To compensate for these imperfections, a specialized high-rate feedback was added at the end of the linac with very fast correctors. It was designed to operate at full rate and remove residual errors caused by the upstream loops. This loop ran with full design gain, while the other feedback used a fraction of the design gain (typically 2.5%).

Figure 1 shows the response of the end of linac feedback to an induced disturbance. It is essentially the design response for a single perfect loop. Figure 2 shows an upstream feedback response to the same step function. The signal shows ringing caused by imperfect upstream feedback loops. This poor mid-linac response caused increased background in the SLD detector, even though the orbit was corrected at the end of the linac.

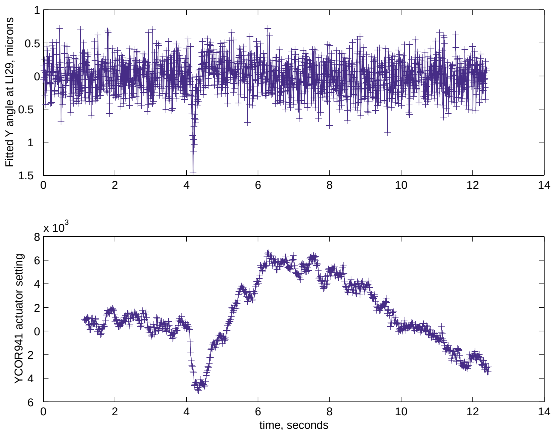

Figure 1: The fast end-of-linac feedback was designed to compensate upstream imperfections. The top figure is the essentially perfect response to a step function. The bottom figure shows the response of one corrector, reacting to the actions of slower upstream feedbacks.

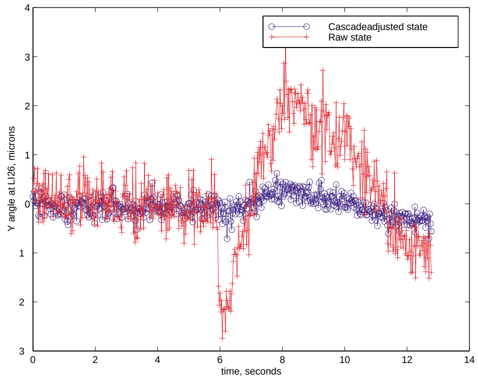

Figure 2: Imperfect feedback system response in the middle of the linac. The "+" figure shows the measured beam response over time. The "o" plot is the residual motion after subtracting upstream information, showing that the cascade system was partially effective.

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2 PERFORMANCE ISSUES

Testing and simulations were performed to understand the performance limitations of the SLC feedback system. Some of the effects studied include:

- Corrector speeds. The slow SLC correctors were not well modeled, contributing to poor single-loop feedback response. Simulations quantified the effect of the corrector speed, and improvements were made to the feedback model.
- Beam transport. Imperfect modeling of the beam transport can result in poor response. A semi-invasive calibration system was developed to measure the actual transport matrices. Future work is planned to investigate methods for adaptively updating the feedback model during routine beam operation.
- Incomplete cascade communication and low gain factors. Full communication of beam information between multiple feedback loops is essential to avoid overcorrection. Lowering the loop gain does not adequately address the problem.
- Device configuration. The SLC feedbacks typically included devices which were physically close together, with large gaps between systems. If the feedback devices are distributed over a larger area, a better linac trajectory can be achieved.

The first three of these problems affect the time response of the system or how quickly a disturbance is fully damped. The transport and device configuration issues affect how well the final orbit is constrained. The last two topics are discussed further below.

3 LINAC CASCADE RESPONSE TEST

The SLC cascade system was implemented to avoid overcorrection by the sequence of feedback systems along the linac. Because of bandwidth and connectivity constraints, a simple one-to-one system was used where each loop only communicated with the next downstream feedback. As later loops were added, the cascade was not implemented for all and the feedback gains were lowered to reduce ringing. To better understand the observed performance of this system, a simplified test was conducted to measure the feedback system response with multiple feedback loops running at low gain factors and with cascade off. As an example, a system of three feedback loops running at gain factors of 0.33 might be expected to have a good system response but performed poorly in the tests.

The test was performed on a series of seven SLC linac feedback loops running at a uniform rate of 5 Hz with the cascade connection turned off. Each loop was configured to use a gain factor of 0.05, so that 1/20 of the design correction was implemented on each pulse. The beam was perturbed by moving an upstream dipole to produce a step function. The response of each feedback system was recorded. For individual loops which showed poor response, the beam transport matrices were recalibrated and the test repeated. The global system response at the end of the linac was essentially unchanged after recalibration. Figure 3 shows the time response for the system. The system overshoots, and ringing continues for about 30 seconds.

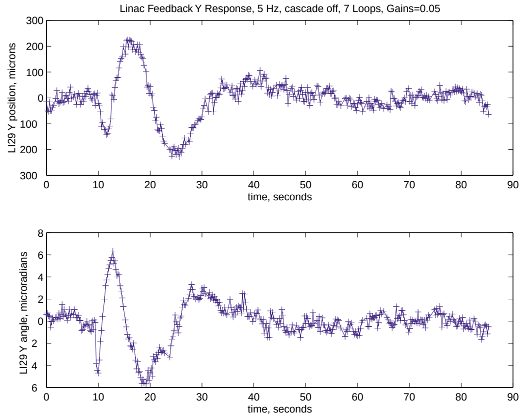

Figure 3: Test response at the end of the SLC linac, for a series of 7 feedback loops without cascade, and with gain factors of 0.05.

To compare with measurements, the NLC linac was simulated with seven feedback loops, similar to the SLC test. The simulation results, shown in figure 4, indicate good general agreement with the beam test. These results support the assumption that the dominant feedback performance problems at the SLC were caused by the sequence of loops operating with an incomplete cascade system.

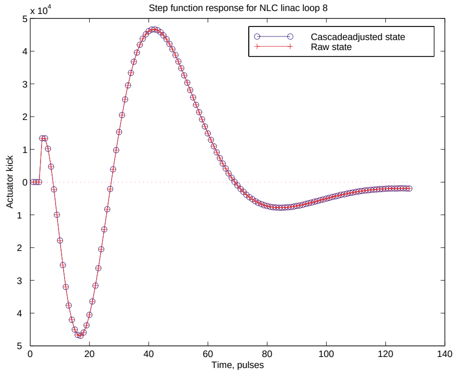

Figure 4: NLC simulation of 7 perfect feedback loops without cascade, with gain factors of 0.05 .

4 MULTICASCADE PROTOTYPE TEST

Another problem with the SLC feedback system performance was due to the combination of wakefields and the correlated energy spread introduced to cancel them. Because the wakefield distortions propagate non-linearly and because the compensating energy spread is largest early in the linac, the beam transport is different depending on where the perturbation begins. A downstream loop must have information from all upstream loops to determine the ideal orbit correction.

Simulations indicate that a feedback system with a many-to-one cascade can avoid overcorrection problems from multiple loops [3,4,5].

A prototype system was implemented and tested in the SLAC linac. Four feedback loops were connected with full multi-cascade communication, so that, for example, the fourth loop received information from all three upstream loops. Because of network limitations this test was run at a rate of 1 Hz. Figure 5 shows the response of the system to a disturbance of the beam upstream of the series of loops.

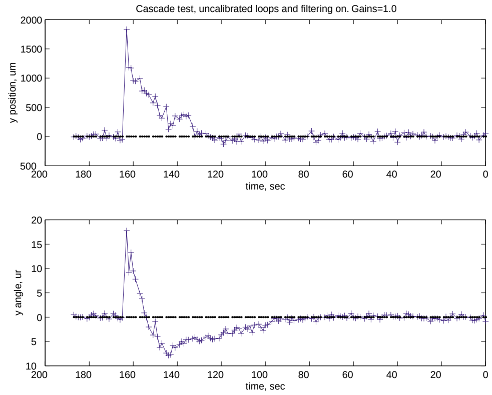

Figure 5: Time response of initial multi-cascade test showing less than perfect behaviour.

The initial test results were not fully satisfactory and two additional modifications were made. First, each feedback was calibrated to measure the actual beam transport matrices. In addition, it was found that cascade had been partly disabled due to exception handling by a filtering option. With the loops calibrated and filtering turned off, the test was repeated. Figure 6 shows the result, which is identical to the design response for a single perfect feedback loop, even though four loops are running with full gain factors.

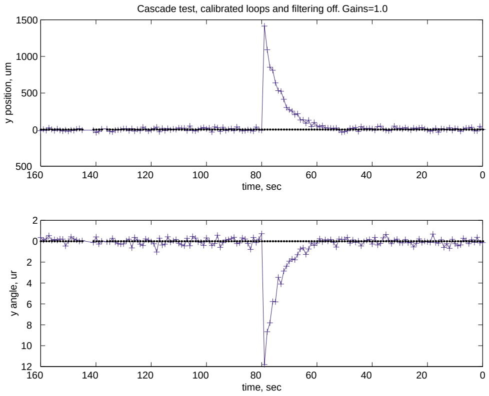

Figure 6: Perfect response of multi-cascade system, after feedback calibration and without filtering.

Future testing is needed to insure that the perfect response is seen at higher intensity when wakefield effects are more significant. In addition, more work is needed on algorithms for adaptively calculating interloop beam transport matrices using beam jitter. Algorithms used for the SLC single-cascade system need to be extended to multi-cascade. Furthermore numerical improvements should be made to insure correct calculations when the beam jitter is small compared to the BPM resolution.

5 DEVICE CONFIGURATION TEST

An experiment was performed to compare the beam trajectories in the SLAC linac for two different device configurations. Traditional SLC feedback loops were distributed over at most two sectors (200 m), constraining the orbit at that location but allowing oscillations to grow elsewhere. Figure 7 shows that a feedback system with devices distributed over a larger area can better flatten the orbit over the entire range.

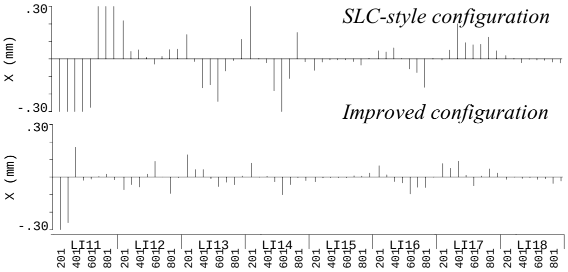

Figure 7: Comparison of two linac configurations. The top figure is the linac trajectory with a traditional SLC-style configuration. Local feedback at linac sectors LI12, LI15 and LI18 allows oscillations to grow between the feedback regions. The second plot shows that a single feedback loop extended over a longer range with distributed BPMs and correctors reduces the average trajectory distortions.

6 SIMULATION VERIFICATION

Tests are in progress to insure that the LIAR simulation code [4] correctly models the linac beam. These tests include studies of the beam orbit response and resulting emittance growth due to an incoming step disturbance.

REFERENCES

[1] L. Hendrickson, et al., "Generalized Fast Feedback System in the SLC," ICALEPCS, Tsukuba, Japan, SLAC-PUB-5683 (1991).

[2] T. Himel, et al., "Adaptive Cascaded Beam-Based Feedback at the SLC," PAC, Washington, D.C., SLAC-PUB-6125 (1993).

[3] P. Tenenbaum, et al., "Use of Simulation Programs for the Modelling of the Next Linear Collider," PAC, New York, New York (1999).

[4] R. Assmann, et al., "The Computer program LIAR for the simulation and modeling of high performance linacs," PAC, Vancouver, Canada (1997).

[5] L. Hendrickson, et al., "Beam-based Feedback Simulations for the NLC Linac," LINAC, Monterey, California (2000).