SLC Experience

- Beam-based feedback used extensively to stabilize energy, trajectory, intensity, collisions, etc.
- Sequence of linac feedbacks used ‘adaptive linear cascade’ to avoid overcorrection by multiple systems
- Still difficulties operating feedback at full design rates, mostly understood from experiments, simulation studies
Experiments

Used SLC system to study feedback behavior

- Ping tests to study time evolution of feedback response
- Frequency tests to map out Nyquist plot
- Different configurations, sample & control rates, gain factors
- Characterization of corrector speeds, modeling errors, BPMs

Test example:
Response of last Linac feedback to an upstream disturbance showing ringing & overshoot due to multiple feedbacks responding to same input

‘Cascade’ between feedbacks Off
Simulations

• Feedback simulations performed using MATLAB for the feedback routines and LInear Accelerator Research tool (LIAR) for the wakefield simulations. Gets simulations running quickly on most platforms

• ATL model of diffusive motion is implemented in simulation codes (ATL model: $\Delta x^2 = A \times T \times L$)

• High frequency ground motion measurements from SLAC site not yet implemented in model (near future)

• Want to do more complete tuning simulation combining LIAR and DIMAD (perhaps driven from MATLAB) —plans not yet complete. Need more understanding of errors
SLC ‘Cascade’ Implementation

• Each feedback sent measured states (position, angle) to next downstream feedback
• Transfer matrices between feedbacks were calculated adaptively from pulse-to-pulse jitter
  note: options constrained by bandwidth & connectivity

Problem 1:
  Wakefields & BNS damping → oscillations propagate differently depending on origin of disturbance

Solution:
  Each feedback must hear from every upstream feedback to identify source of disturbance and proper transport
Time evolution of Linac feedback response to a step disturbance.

SLC configuration with 1-to-1 cascade and localized correctors and BPMs for each feedback.

Later feedbacks overshoot & ring. Oscillation does not fully damp even after > 20 pulses.
Time evolution of Linac feedback response to a step disturbance.

Proposed NLC configuration is many-to-1 cascade with distributed correctors and BPMs for each feedback.

Oscillation damps in a few pulses.

Distance along main Linac in km
SLC Feedback Calculation

- Feedback intended to minimize RMS of BPM offsets
- SLC feedback fit BPM readings to stabilize position, angle at a particular location
- This did not always result in minimum BPM RMS

**Problem 2:**
- Sensitivity to model errors, errant BPMs
- Numerical stability of solution

**Solution (for now):**
- Fit for corrector setting to minimize BPM RMS
  appears to give a more stable solution, still under study
SLC Feedback Configuration

- Each feedback used short range of BPMs with correctors immediately upstream (to minimize network links)
- Oscillations grew immediately downstream of feedback

**Problem 3:**

Feedback corrects centroid of beam but not tilt (e.g. $y$-$z$ correlations) caused by wakefields
Tail of beam continues to be kicked after correction

**Solution:**

Each feedback uses a distributed set of BPMs and correctors to effectively minimize both centroid and tilt
Feedback OFF simulation

Response to a perturbation early in NLC main linac

BPM readings are in blue

Feedback locations shown in red

BNS damping reduces amplitude

Distance along main Linac in km
SLC style Feedback ON simulation

Feedback BPMs and correctors localized

Oscillation grows downstream of each feedback due to Y-Z tilt caused by wakefields

Final amplitude larger than feedback off

Distance along main Linac in km
NLC style
Feedback ON simulation
Feedback BPMs and correctors distributed
Dotted lines show location of extra BPMs and correctors
Oscillation well controlled even early in Linac

Distance along main Linac in km
Test of SLC & NLC layouts

Response to an incoming X oscillation with SLC localized feedback compared with NLC distributed feedback

Red arrows show location and length of feedback regions
Blue arrows show locations of BPMs, Green arrows correctors
Luminosity Optimization

To optimize SLC luminosity, 5 correction knobs/beam were used routinely – X/Y waist, X/Y dispersion, coupling

**Old method:**
Automated scan of beam size vs knob measured with deflection scan, but for small beams, poor resolution (1 mm on Y waist) + luminosity loss w/ scan

**Solution:**
Feedback which ‘dithers’ knobs, 1 at a time, maximizes signal ∝ luminosity
**Benefits:**
Resolution improved * 10 (0.1 mm Ywaist)
Large # of samples gives high precision even with a noisy signal
High resolution used to align FF sextupoles, octupoles, geometric sextupoles
Operational - all crews tune equally + freed up almost 1 FTE for other tuning
Technique also tried for wakefield cancellation but not fully commissioned

**Result:** Luminosity loss from mis-optimization reduced to a few %
Technique with wide applicability in future linear colliders
Summary

• SLC feedback was invaluable but performance not optimal
• Simulations (Matlab/LIAR) and Experiments have led to greater understanding of many problems/issues
  – non-linear many-to-1 cascade
  – distributed correctors and BPMs to cancel tilt as well as offset
  – numerical stability problems with calculation
  – corrector speed modeling and matching
  → implications for required network connectivity and bandwidth
• ‘dither’ optimization feedback is a powerful tool for LCs

Still more work to be done