

SIMULATIONS OF IP FEEDBACK AND STABILIZATION IN THE NLC *

L. Hendrickson#, J. Frisch, T. Himel, T. Raubenheimer, A. Seryi, M. Woodley, SLAC, Menlo Park, California, USA

G. White, Queen Mary University of London, London, England

Abstract

Keeping nanometer-sized beams in collision is an essential component in achieving design luminosity in a linear collider. The NLC stabilization strategy is conservative by including enough redundancy so that if some part does not work to specification or the incoming beam motion is worse than expected, the beams will still be kept in collision. We show simulation results with both realistic and pessimistic assumptions about the response of the ground motion, inertial stabilization, intratrain and intertrain feedback systems. By providing backup systems, and by allowing some systems to perform more poorly than design, it is possible to have a high level of confidence that the beams can be stabilized successfully.

INTRODUCTION

Keeping nanometer-size beams colliding is a significant challenge, but complementary techniques have already shown feasibility. Several R&D projects have made excellent progress toward demonstrating the components needed to meet the requirements. The bottom line for a linear collider is integrated luminosity. Therefore, it is worthwhile to estimate the impact on luminosity, with differing assumptions for the planned components. We assume the use of 120-Hz intertrain deflection feedback, which was well-demonstrated in the SLC [1]. The additional techniques evaluated are:

- Intratrain feedback, which acts on individual bunches [2],
- Inertial stabilization, which actively stabilizes the final doublet magnets [3]
- Choice of quiet site, with a well-engineered detector for low vibration.

For moderate ground motion models (similar to the SLAC site) [4], simulations show that with ideal versions of any two of the three techniques, the resulting luminosity is greater than 90% of design. If only one approach is used, the luminosity is greater than 66%. However, if all three techniques are evaluated according to measured results from the R&D testing, the resulting luminosity is 90% of design. This result is an excellent beginning, and further improvements in the results are anticipated.

INTRATRRAIN FEEDBACK SYSTEMS

Intertrain feedback operates on entire pulse trains to keep the trains in collision at the 120-Hz pulse rate of the NLC. It is based upon the same design which was successfully used in the SLC [1]. It is essential to the operation of any linear collider, and its use is assumed in

*Work supported by the U.S. Department of Energy under contract number DE-AC03-76SF00515.

#ljh@slac.stanford.edu

all simulation results. As a result of the SLC experience, there is a high degree of confidence in the success of this technique. The feedback system uses beam position monitors (BPMs) on both sides of the interaction point (IP) to determine the mutual deflection of the beams. Theoretically, there would be zero deflection when the beams are perfectly colliding, but there are two complications. First, the BPMs have electronic and alignment offsets which are unknown and may change with time. Second, due to imperfect alignment of the accelerator, the bunches are likely to be non-Gaussian in shape, and therefore the collision point which provides maximum luminosity will not have zero deflection. In the SLC, the optimal collision point was found by scanning the beams across one another and fitting an "S" shaped deflection curve. For NLC, the plan is to scan one of the beams across the other, and find the point of maximum luminosity.

The design of the intertrain feedback system can be optimized to coordinate with the expected response of the other systems. Figure 1 shows two typical design responses. Note that each of these designs damp low frequency noise, while amplifying at high frequencies (typically above 10 Hz).

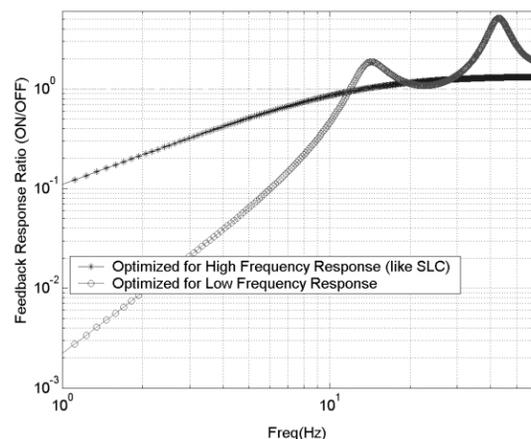


Figure 1: Design responses for 120-Hz intertrain feedback. The SLC-type design (*) is optimized for high frequency noise. An alternative design (o) is optimized for improved low frequency response, and is appropriate for use with the current measured stabilization data.

INTRATRRAIN FEEDBACK SYSTEMS

The intratrtrain feedback is a hardware-based system which acts on the individual bunches of the train, with extremely high bandwidth. The interbunch spacing for the NLC is 1.4 ns, and there are nearly 200 bunches, so the entire bunch train passes within 270 ns. Experiments have demonstrated the low-latency response of prototype hard-

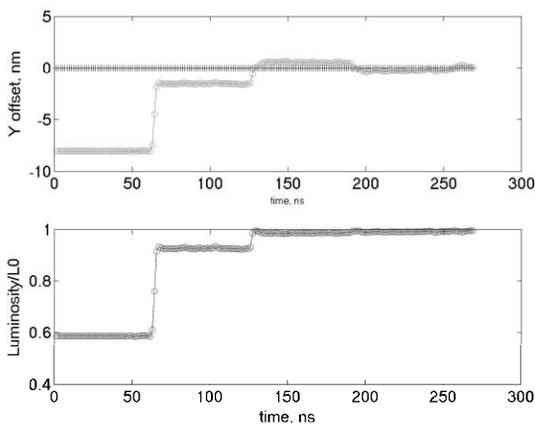


Figure 2: Measured response of intratrain feedback. Response to 8 nm offset of one beam, assuming measured response time of ~62 ns. This includes estimated time-of-flight for the planned NLC layout.

ware. This increases confidence in the system. These experiments have been performed both at the NLCTA facility at SLAC [2], and at the ATF test facility at KEK. Preliminary results are excellent, and improved latency is expected with currently planned upgrades to the electronics [5]. Figure 2 shows the measured latency.

INERTIAL STABILIZATION

In the NLC beam delivery design, any motion of the final doublet magnets has a significant impact on jitter at the IP. R&D work at SLAC has demonstrated stabilization of a prototype object, with a cantilevered design similar to the final doublet [3]. The prototype object is about 3 meters long, and approximately the same size and weight as the doublet with its support tube. The stabilization system operates at 1-2 KHz, and uses electrostatic pusher plates to damp motion measured by geophones and accelerometers. An additional project has developed an excellent low-noise prototype sensor, which is non-magnetic and can fit into the detector environment [6].

Figure 3 shows integrated measured motion of the prototype object, compared to the ground motion. The mechanical design of the object, which is a mass on springs, translates high frequency motion to lower frequencies, where it is effectively controlled by both the active stabilization and the 120 Hz feedback systems. The remaining 10 Hz noise on top of the object is due to the realistic cantilevered design, which is necessary for use inside the detector. New techniques are currently being developed to improve the 10 Hz response. In addition, efforts are underway to characterize and improve the higher-frequency residual motion.

To evaluate the effect of the residual final doublet motion on luminosity, measurements from an independent low-noise sensor on top of the object are converted to absolute motion, and input to the MatLiar simulations. This provides the “measured” data for both the detector noise and the stabilization assumptions. No correlation between

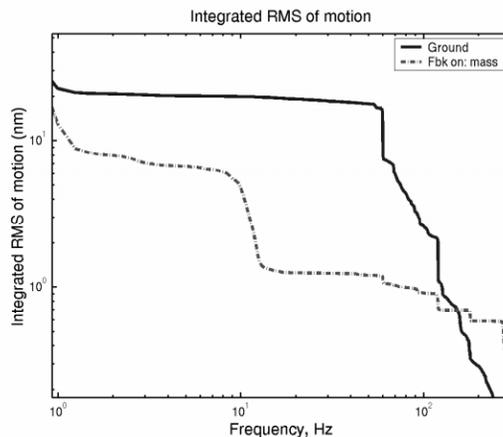


Figure 3: Integrated motion (nanometers), with active stabilization of the final doublet prototype.

the two final doublets is assumed, and independent measurements are used for motion on each side of the IP. This measurement, taken in the very noisy NLCTA lab, provides a very conservative estimate of stabilization and detector noise.

In the luminosity simulations, “ideal” stabilization is modeled using a design with the best commercial sensors.

QUIET SITE AND DETECTOR DESIGN

It is desirable to select a quiet site for the machine, and to design the detector to minimize vibration. Many studies have been performed to characterize the vibration characteristics for sites around the world. These are shown in Figure 4. Most proposed sites for the NLC are quieter than SLAC, which is used for the moderate-noise simulations. Detector motion of 20 nm was measured on the SLD detector at SLAC, and simulations for a “quiet” detector assume 4 nm of detector motion.

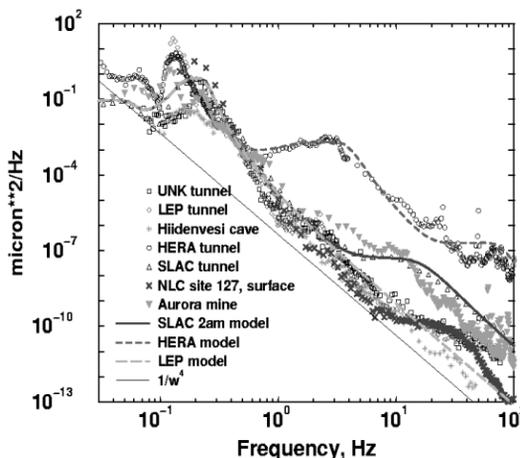


Figure 4: Ground motion measurements at various sites. SLAC 2am model is used for moderate-noise simulations.

SIMULATION OVERVIEW

Luminosity simulations are performed using the MatLiar system [7], which runs within the Matlab [8] environment, and includes full 2-beam tracking through the linac and beam delivery systems, with wakefield

modeling, feedback algorithms and simulation of beam-beam deflection effects [9].

SIMULATION RESULTS FOR MODERATE GROUND MOTION

Luminosity simulations have been done for a wide variety of assumptions. Results shown in Table 1 are for moderate (SLAC-type) ground motion. 90% of peak luminosity is achieved for the case where measured results are used for all 3 techniques. Assuming the ideal performance of any two techniques, the resulting luminosity is over 90%.

Final Doublet Jitter	Stabilization	Intratraining Feedback	Linac/BDS Jitter	Lumi (%)
20nm**	No	No	Nominal	30
NLCTA average*	Meas*	No	Nominal	59
4nm	No	No	Nominal	66
NLCTA quiet*	Meas*	No	Nominal	69
20nm**	Ideal	No	Double	78
20nm**	No	Ideal	Nominal	81
20nm**	Ideal	No	Nominal	90
NLCTA average*	Meas*	Meas*	Nominal	90
4nm	Ideal	No	Nominal	91
NLCTA quiet*	Meas*	Meas*	Nominal	92
4nm	No	Ideal	Nominal	95
20nm**	Ideal	Ideal	Double	98
20nm**	Ideal	Ideal	Nominal	99

Table 1: Resulting luminosity for moderate ground motion, for different assumptions of stabilization techniques.

* = measured in NLCTA prototype testing.

** = 20 nm detector movement measured on SLD at SLAC.

SIMULATION RESULTS FOR LARGE GROUND MOTION

For noisy sites such as those proposed at KEK, stabilization is particularly challenging. However, simulations using measurements which have already been achieved would indicate the feasibility of operation at such a site. In particular, for the KEK ground model [10] which has large motion, using jitter and stabilization measurements taken from the NLCTA testing, and estimated intertrain feedback response as measured with NLCTA experiments, it is estimated that 88% of full luminosity is maintained. Further improvements are expected with additional R&D progress. Table 2 summarizes these results.

Final Doublet Jitter	Stabilization	Intratraining Feedback	Lumi (%)
20nm**	No	No	30
NLCTA*	Meas*	No	56
4nm	No	No	60
20nm**	No	Ideal	81
20nm**	Ideal	No	70
NLCTA*	Meas*	Meas*	88
4nm	Ideal	No	70
4nm	No	Ideal	92
20nm**	Ideal	Ideal	94

Table 2: Resulting luminosity for large (KEK) ground motion, for different assumptions of stabilization techniques.

* = measured in NLCTA prototype testing.

** = 20 nm detector movement measured on SLD detector

SUMMARY

Intratraining feedback, inertial stabilization and a quiet site and detector are all elements in a strategy to maintain high luminosity for the NLC. However, for moderately quiet sites, only two of the 3 elements are needed in order to maintain >90% of full luminosity. More importantly, simulations using measured results for all 3 elements give 88% of full luminosity even for a noisy site, and 90% for a moderate site. These results support a high degree of confidence in the ability to stabilize nanometer-sized NLC beams for a variety of sites.

REFERENCES

- [1] L. Hendrickson, et al., "Generalized Fast Feedback System in the SLC," ICALEPCS, Tsukuba, Japan, SLAC-PUB-5683 (1991)
- [2] P. Burrows, "Nanosecond-timescale Intra-bunch-train Feedback for the Linear Collider: Results of the FONT2 Run," in these proceedings.
- [3] J. Frisch, et al., "Active Vibration Suppression R&D for the Next Linear Collider," PAC2001, Chicago, SLAC-PUB-9419.
- [4] A. Seryi, et al., "Simulation Studies of the NLC with Improved Ground Motion Models," LINAC, Monterey, California (2000).
- [5] P. Burrows, private communication, May, 2004.
- [6] J. Frisch, et al., "Inertial Sensor Development for Active Vibration Stabilization," PAC03, Portland, OR, SLAC-PUB-9843 (2003).
- [7] P. Tenenbaum, et al., "Use of Simulation Programs for the Modeling of the Next Linear Collider," PAC, NY, NY (1999).
- [8] <http://www.mathworks.com/>
- [9] http://www-project.slac.stanford.edu/lc/bdir/programs/guinea_pig/gp_index.html
- [10] A. Seryi, et al., "Vibrational Stability of GLC/NLC Linear Collider: Status and R&D Plans," in these proceedings.