# Simulation Studies of the NLC with Improved Ground Motion Models *

A. Seryi, L. Hendrickson, P. Raimondi, T. Raubenheimer, P. Tenenbaum
*Stanford Linear Accelerator Center, Stanford University, Stanford, California 94309 USA*

*Abstract*

The performance of various systems of the Next Linear Collider (NLC) have been studied in terms of ground motion using recently developed models. In particular, the performance of the beam delivery system is discussed. Plans to evaluate the operation of the main linac beam-based alignment and feedback systems are also outlined.

## 1 INTRODUCTION

Ground motion is a limiting factor in the performance of future linear colliders because it continuously misaligns the focusing and accelerating elements. An adequate mathematical model of ground motion would allow prediction and optimization of the performance of various subsystems of the linear collider.

The ground motion model presented in [9] is based on measurements performed at the SLAC site and incorporates fast wave-like motion, and diffusive and systematic slow motion. The studies presented in this paper include, in addition, several representative conditions with different cultural noise contributions. These models were then used in simulations of the NLC final focus and the main linac.

## 2 GROUND MOTION MODELS

The ground motion model for the SLAC site [9] is based on measurements of fast motion taken at night in one of the quietest locations in the SLAC, sector 10 of the linac [5].

To evaluate different levels of cultural noise, we augment this model to represent two other cases with significantly higher and lower contributions of cultural noise. The corresponding measured spectra and the approximations used in the models are shown in Fig.1.

The "HERA model" is based on measurements in DESY [3] and corresponds to a very noisy shallow tunnel located in a highly populated area where no precautions were made to reduce the contribution of various noise sources in the lab and in the tunnel. The "LEP model" corresponds to a deep tunnel where the noise level is very close to the natural seismic level, without additional cultural sources outside or inside of the tunnel. The "SLAC model" represents a shallow tunnel located in a moderately populated area with a dead zone around the tunnel to allow damping of cultural noise and with some effort towards proper engineering of the in-tunnel equipment. (Note: the names of these models were used for convenience, and not to indicate the acceptability of each particular location.)

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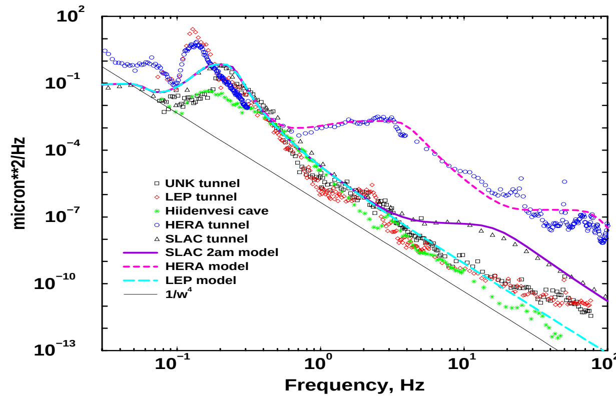


Figure 1: Power spectra measured in several places in different conditions [1, 3, 5, 2] and the approximation curves.

The correlation properties of the "LEP model" correspond to a phase velocity $v = 3000$ m/s [1]. Both the "SLAC model" and the "HERA model" use a phase velocity corresponding to $v(f) = 450 + 1900\exp(-f/2)$ (with $v$ in m/s, $f$ in Hz) which was determined approximately in the SLAC correlation measurements [5]. This approximation was found to be suitable for representing the DESY correlation measurements [3], at least for frequencies greater than a few Hz, which contain most of the effects of the cultural noise.

## 3 APPLICATIONS TO FFS

The ground motion models developed were applied to two versions of the NLC Final Focus, to the one described in Ref. [5] as well as the current FFS described in Ref. [10]. The FF performance is usually evaluated using the 2-D spectrum $P(\omega, k)$ given by the ground motion model plus spectral response functions which show the contribution to the beam distortion at the IP of different spatial harmonics of misalignment.

We summarize below the basics of the approach developed in [2, 4] and [5]. Considering a beamline with misaligned elements, as in Fig.2, the beam offset at the exit of the beamline and the dispersion (for example) can be evaluated using

$$x^*(t) = \sum_{i=1}^{N} c_i\, x_i(t) - x_{\mathrm{fin}} \quad \text{and} \quad \eta(t) = \sum_{i=1}^{N} d_i\, x_i(t)$$

where $c_i = dx^*/dx_i$ and $d_i = d\eta/dx_i$ are the coefficients found using the parameters of the focusing elements and the optical properties of the channel. In a thin lens approximation to linear order, $c_i = -K_i\, r_{12}^i$ and $d_i = K_i\,(r_{12}^i - t_{126}^i)$. Here $K_i$ is $r_{21}$ of the quad matrix, and $r_{12}^i$ and $t_{126}^i$ are the matrix elements from the $i$-th quadrupole to the exit. Fig.3 shows the $c_i$ coefficients calculated for the new NLC Final Focus [10].

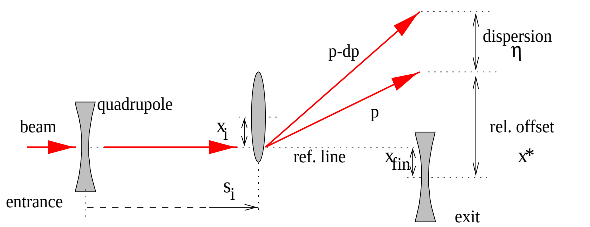


Figure 2: Schematic showing how quad misalignments result in the beam offset and dispersion.

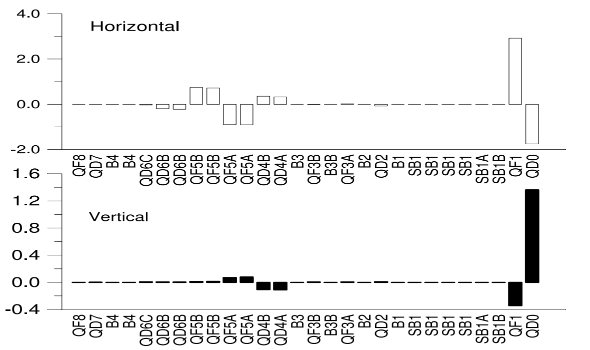


Figure 3: Coefficients $c_i = dx_{\rm IP}/dx_i$ for the new NLC Final Focus. Computed using FFADA program [6].

It is straightforward then to combine these coefficients into the spectral response functions which show the contribution of misalignment spatial harmonics to the relative beam offset or to the beam distortion at the IP. For example, for the dispersion:

$$G_\eta(k) = \left(\sum_{i=1}^{N} d_i(\cos(ks_i) - 1)\right)^2 + \left(\sum_{i=1}^{N} d_i \sin(ks_i)\right)^2$$

The spectral functions for the relative beam offset, longitudinal beam waist shift or coupling can be found in a similar manner and examples of the spectral functions for the new NLC FF are shown in Fig.4.

The time evolution of the beam dispersion, without the effect of feedbacks, can then be evaluated using

$$\langle \eta^2(t) \rangle = \int_{-\infty}^{\infty} P(t,k)\, G_\eta(k)\, \frac{dk}{2\pi}$$

where $P(t,k)$ represents a $(t,k)$ incarnation of the ground motion spectrum $P(\omega,k)$:

$$P(t,k) = \int_{-\infty}^{\infty} P(\omega,k)\;\; 2\left[1-\cos(\omega t)\right] \frac{d\omega}{2\pi}$$

In the case where a feedback with a gain of $F(\omega)$ is applied, the equilibrium beam offset can be evaluated as

$$\langle \Delta x^{*2} \rangle \approx \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} P(\omega,k)\, F(\omega)\, G(k)\, \frac{d\omega}{2\pi}\, \frac{dk}{2\pi}$$

though more realistic simulations would be necessary to produce a reliable result. In the examples given below, we used an idealized approximation of the feedback gain function $F(\omega) = \min((f/f_0)^2, 1)$ with $f_0 = 6$ Hz; this is a good representation of the SLC feedback algorithm for 120 Hz operation.

Such analytical evaluation of ground motion, using the $P(\omega,k)$ spectrum and the spectral response functions for

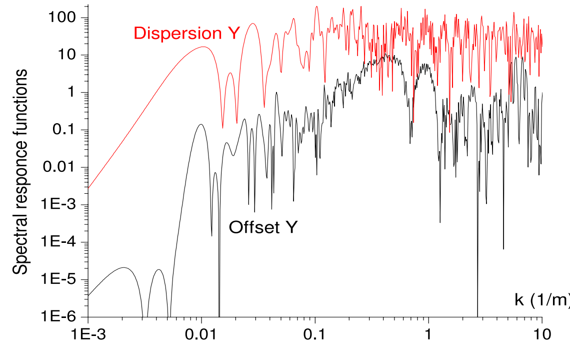


Figure 4: Spectral responce functions of New NLC FF.

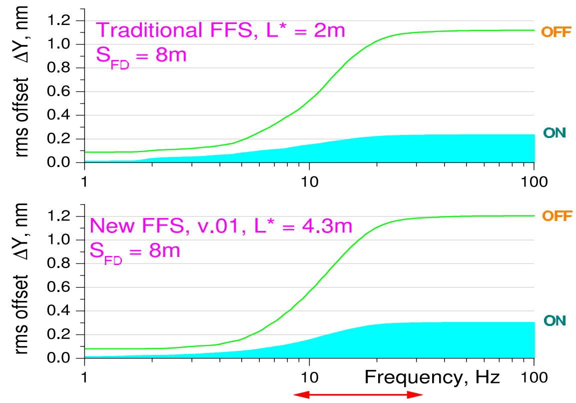


Figure 5: Integrated spectral contribution to the rms equilibrium IP beam offset for the traditional and new Final Focus for the SLAC 2AM ground motion model. Idealized rigid supports of the final doublets are assumed to be connected to the ground at $\pm S_{\rm FD}$ from the IP. The relative motion of the final doublets is completely eliminated in the case "ON". Red arrow shows the region of frequency giving the largest contribution to the rms offset.

the transport lines is included in the PWK module of the final focus design and analysis code FFADA [6].

Evaluation of the traditional and new Final Focus in terms of the rms beam offset for the "SLAC model" is shown in Fig.5. One can see that in terms of generalized tolerances these two systems are very similar. However, in the new system which has longer $L^*$, more rigid support can be used for the final doublet which makes the performance closer to the ideal. One can also see that if one could eliminate the contribution from the final doublet by active stabilization, it would remove about 80% of the effect.

The free IP beam distortion evolution for the traditional and new NLC FF is shown in Fig.6 for the "SLAC model". Note that an orbit correction which could keep the orbit stable through the sextupoles would drastically decrease this beam distortion. The picture presented is therefore useful only for comparison of the performance of the two FF systems. One can see, that the new FF, having longer $L^*$ and correspondingly higher chromaticity, has somewhat tighter tolerances. The orbit feedback, however, may be much simpler since there are fewer sensitive elements in the new system.

The analytical results presented in Fig.6 are in good agreement with the tracking. One should note here that

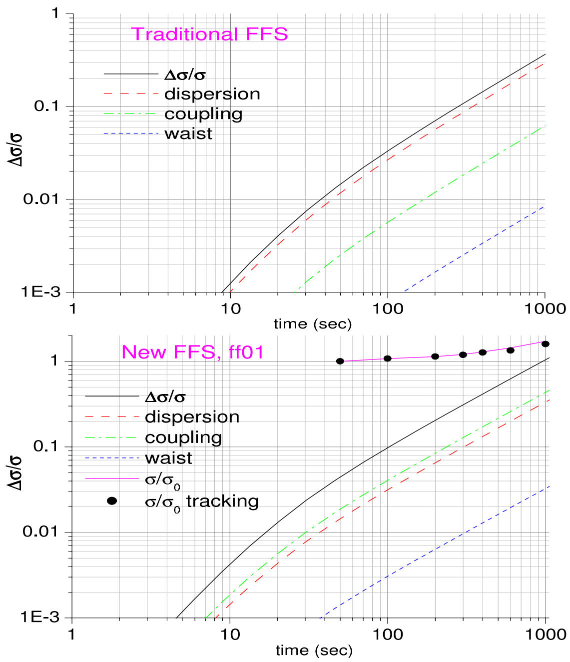


Figure 6: Beam distortion at the IP for the traditional and new NLC FF versus time for the "SLAC model" of ground motion, free evolution. Note that orbit feedback would drastically decrease this beam distortion. Results were computed using the FFADA program [6].

the tracking was done with an energy spread which is 3 times smaller than nominal (see [10] for these beam parameters) because otherwise the second order tracking routine of the MONCHOU program used for misalignment simulation did not produce reliable results when compared with other programs.

Comparison of the performance of the new FF in terms of different ground motion models is shown in Fig.7. One can see that a site located in a highly populated area without proper vibration sensitive engineering would present significant difficulties for a linear collider with the parameters considered. Stabilization of only the final doublet would not be sufficient in this case. A site with noise similar to

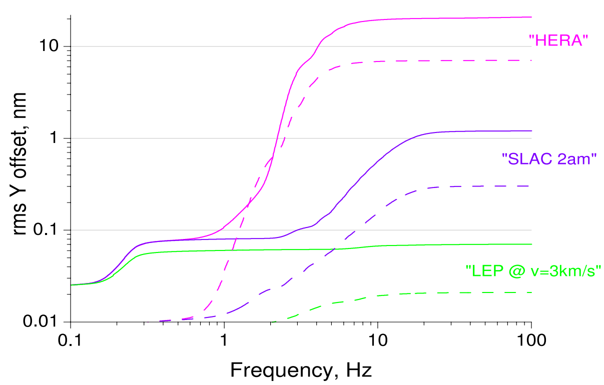


Figure 7: Integrated spectral contribution to the rms equilibrium IP beam offset for the new Final Focus with FD supports at $S_{\rm FD} = \pm 8$ m for different models of ground motion. Dashed curves correspond to the complete elimination of relative motion of the final quads.

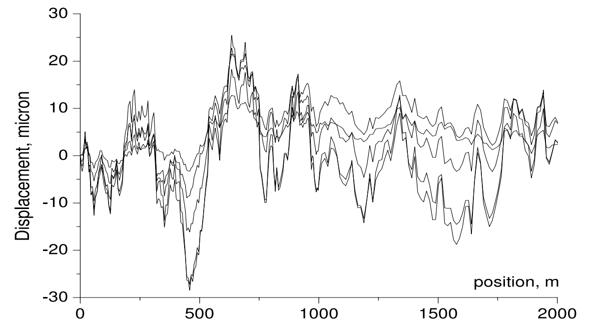


Figure 8: LIAR generated misalignments of a linac for "SLAC model" and $\Delta T = 8$ hours between curves.

the "SLAC model" would certainly be suitable, while the "LEP model" would be suitable even for much more ambitious beam parameters. These results should not be considered as an attempt to evaluate any particular site, or even the models, because for a fully consistent assessment, various in-tunnel noise sources as well as vibration compensation methods must be considered together.

## 4 APPLICATIONS TO LINAC

The models now developed, which more adequately describe the various components of ground motion, can also be applied to simulations of the beam based alignment procedures and cascaded feedback in the main linac. Such simulations require direct modeling of misalignments which is done by summing harmonics whose amplitudes are given by the 2-D spectrum of the corresponding ground motion model. In this case, since a large range of $T$ and $L$ must be covered in a single simulation run, the harmonics are distributed over the relevant $(\omega, k)$ range equidistantly in a logarithmic sense [8]. Such a method of ground motion modeling is now included in the linear accelerator research code LIAR [7] in addition to the previously implemented ATL model. An example of the misalignments generated by LIAR is shown in Fig.8.

## 5 CONCLUSION

New ground motion models now incorporate various sources of ground motion such as wave-like motion, diffusive and systematic motion. These models are being used to evaluate and optimize performance of various subsystems of the NLC.

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