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Ground Motion Studies and Modeling for the Interaction Region of a Linear Collider

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Ground Motion Studies and Modeling for the Interaction Region of a Linear Collider *

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Abstract

Ground motion may be a limiting factor in the performance of future linear colliders. Cultural noise sources, an important component of ground motion, are discussed here, with data from the SLD region at SLAC.

1 INTRODUCTION

Ground motion may be a limiting factor in the performance of future linear colliders because it causes continuous misalignment of the focusing and accelerating elements. Understanding the ground motion, including finding driving mechanisms for the motion, studying the dependence on geology, local engineering, etc., and creating ground motion models that permit evaluation of the collider performance, are essential for the optimization of the linear collider.

There has been a lot of progress in understanding motion of the ground and its modeling in recent years, which has allowed us to build both general and specific ground motion models for a particular location. For example, the model presented in [1] includes systematic, diffusive, and fast motion based on various measurements performed at the SLAC site.

However, several important features are not sufficiently well studied and consequently are not yet adequately represented in this (or other) models or in the underlying analytical approach. Proper representation of cultural noise is a major concern. The model mentioned above is based on measurements of the fast motion performed at night in sector 10 of the SLAC linac [2], one of the quietest locations at SLAC. The corresponding model of the correlation is suitable for the case when the noise sources are located remotely from the points of observation. Cultural noise may not only increase the fast frequency power spectrum, for example as shown in Fig.2, but also the correlation model may have to be changed if the noise sources are located in the vicinity of or between the points of interest. Cultural noise sources, located above or inside the tunnel, can locally increase the amplitudes of motion. The model, and the analytical framework, however, assume that the spectrum of motion or the correlation do not depend on location, which is natural for the spectral approach based on the use of the 2-D spectrum $P(\omega, k)$, which cannot depend on position. This issue should be handled by use of a local addition $p(\omega, s)$ to the spectrum which would describe (together with corresponding correlation information) each noise source located in the vicinity. Here $\omega = 2\pi f$, f – frequency, k – wavenumber, s – position. See [4] for more detailed definitions. In some cases, a function $\psi(\omega, s)$ which would characterize local amplification of vibrations, for example due to the resonant properties of girders, should also be used.

Cultural noise in the detector area of a linear collider is of special concern. The most severe position tolerances are for the final quadrupoles. Various systems of the detector and the detector hall will unavoidably alter the natural "quietness" of the area.

Studies of vibration noise have recently been performed in the HERA Hall East [7]. The observed motion at HERA was found to be quite large, for example the rms motion above 1 Hz reachs 100–200 nm. This high level of vibrations at HERA appears to be caused by the high urbanization of the area.

In the studies presented below noise in the SLAC Large Detector has been investigated.

2 NOISE IN SLD DETECTOR AREA

Vibrations studies are currently being performed in the SLD pit at SLAC. The SLD detector is shutdown and represents an ideal test bench for such studies. Eight seismoprobes have been installed in the detector area. Two broadband Streckeisen STS-2 seismometers are placed under the detector on the concrete floor with 14 m separation between them as shown in Fig.1. Four Mark L4 geophones are placed in the final focus tunnels, and two piezosensors on the superconducting triplet and on the detector itself. The complete results of these studies in the SLD hall will be reported elsewhere [3]. We present here only the results for the floor vibration under the detector.

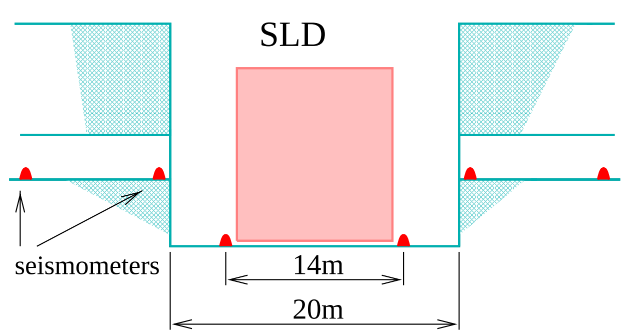

Figure 1: Schematics of SLD area showing location of seismoprobes installed on the floor of the pit and in final focus tunnels. The doors of the detector, the superconducting triplets and probes installed on them are not shown.

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The power spectra measured by the STS-2 probes during day and night is shown in Fig.2. The high frequency part of the spectra ($F \gtrsim 10$ Hz) is clearly much noisier than that measured in sector 10. However, the day-night variation is absent, which means that this noise is produced mostly by local (in the SLD building and nearby vicinity) sources, while the contribution from more remote sources (traffic, etc.) is much less pronounced. On the other hand, the low frequency contribution of the traffic and other cultural noises produced inside and outside of SLAC has clear day-night variations, as seen in Fig.2,3 and 4.

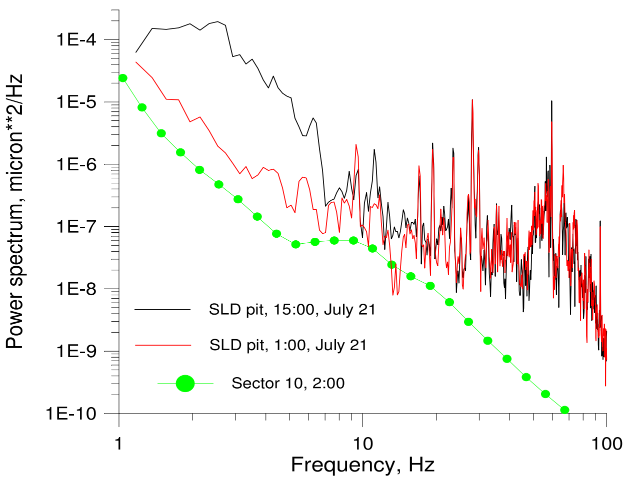

Figure 2: Power spectra measured at 2a.m in SLAC sector 10 [2] compared with spectra measured by the STS-2 probe placed on the concrete floor under the South door of the SLD detector.

The integrated amplitude shown in Fig.3,4 and 5 is defined as the integral over the power spectrum from a specific frequency F to a maximal frequency:

$$\mathrm{rms} = \left(\int_{F}^{F_{max}} p(f) df \right)^{1/2} .$$

One should note that the rms amplitude of the difference of displacements of two points, in the case where these motions are uncorrelated, can exceed each of the individual rms values (for example by a factor of $\sqrt{2}$ if these two rms values are equal). The motion under the South and North part of the SLD detector, shown in Fig.5, is mostly uncorrelated for frequencies higher than about 4 Hz, as seen in Fig.6, though at some particular frequencies the correlation is noticably nonzero even for $f \gtrsim 4$ Hz. For identical probes the imaginary part of the correlation must be zero if the power spectra in the two places are equal [4]. One can see in Fig.5 that these power spectra are, in fact, quite different and so the imaginary part of the correlation shown in Fig.6 is essentially nonzero.

The measurements presented in Fig.2, 3 and 4 were performed when most of the SLD electronics was on (with its local ventilation) and the building ventilation operating. The water flow in the SLD conventional solenoid was set to one third of the nominal level, approximately 300 gallons per minute. The floor motion was found to be greatly influenced by the ventilation system of the building (located in the North part of the SLD hall) and, to a lesser extent, by the SLC and SLD water pumps located about 20 m North of the building.

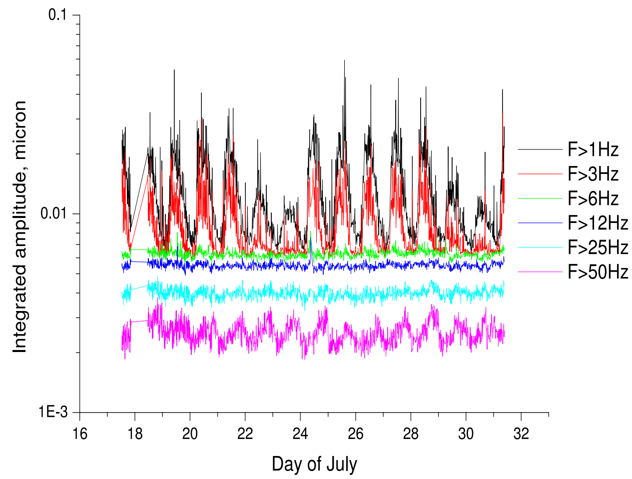

Figure 3: Rms amplitudes in different frequency bands measured by the STS-2 probe placed on the concrete floor under the North door of the SLD detector in July 2000.

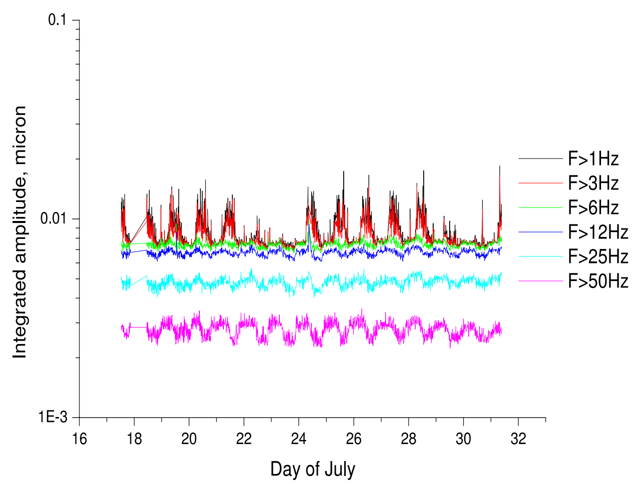

Figure 4: Rms amplitudes in different frequency bands of the difference of displacement measured by two STS-2 probes placed with 14 m separation on the concrete floor under the South and the North doors of the SLD detector.

The NLC, operating at a repetition frequency of 120 Hz, will be sensitive to the jitter of its final focusing doublet at frequencies above approximately 6 Hz (beam-based feedback can presumably take care of the beam offsets below this frequency). As we see from the Fig.4, even without any significant precautions to reduce the noise, the difference of the floor motion measured by the two STS-2 probes separated by 14 m is about 8 nm for $F \gtrsim 6$ Hz, which is roughly twice the typical NLC vertical beam size.

By turning off most (but still not all) of the equipment, including the SLD and SLC water pumps, the building ventilation and most of electronics (which would require proper engineering of these subsystems for NLC) this dif-

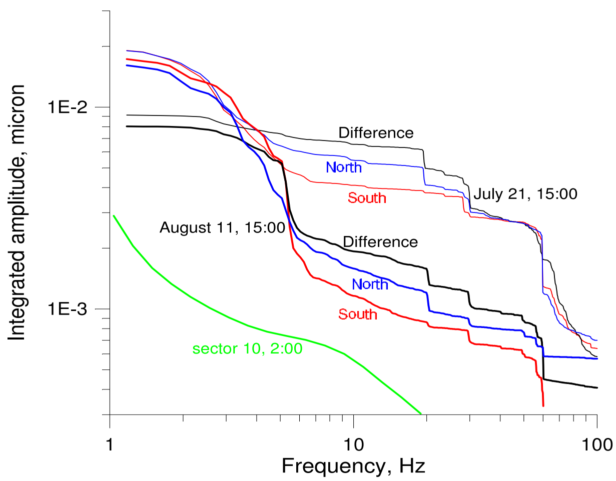

Figure 5: Integrated spectrum (amplitude for $F > F_0$) corresponded to measurements in SLAC sector 10 at 2:00 compared with the spectra measured by probes placed under the SLD detector with 14 m separation at 15:00 on July 21 and at 15:00 on August 11; most of the noise sources in the building turned off at this later date.

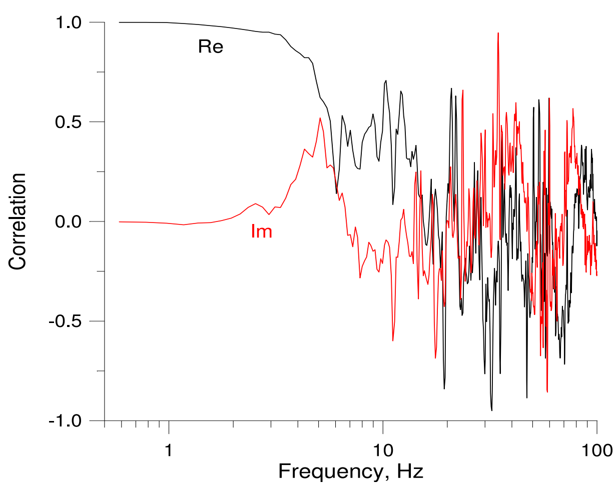

Figure 6: Correlation (real and imaginary parts) of the motion measured by the STS-2 probes placed under the SLD detector with 14 m separation on August 11. Averaged over 123 files with 30 seconds record length.

ference can be decreased to about 2 nm [3]. As we see in Fig.5, even in this case, the North probe, located closer to the noisier North part of the building, shows larger vibrations. Therefore, further reduction of the difference value would seem to still be possible.

Of course the motion of the final quadrupoles cannot be as low as the motion of the floor because the supports cannot be made ideally rigid. The strategy we consider involves active stabilization of the final quadrupoles by using inertial sensors possibly in combination with an optical reference to the ground. In one of the proposals [5] the optical path would pass from the final quadrupoles through the detector to a common location under the detector. This has the disadvantage of putting significant constraints on the detector design. Such a configuration of the detector is now considered unlikely to be necessary.

However, if the optical reference is desired in addition to the inertial sensors to improve the performance of the inertial stabilization, the optical reference can be made to the floor (possibly to local pits) under each of the final quadrupoles (approximately at the same positions where the STS-2 probes were placed in our measurements). The necessary correction of the differential motion of the floor could then be done by using seismometers located at these reference locations. One can see that in the conditions similar to those of the SLD area, where the spectrum of motion drops quite rapidly with frequency, this strategy would work even without significant additional engineering for noise reduction.

The optical path for the reference to the ground could be located outside of the detector, greatly simplifying its design and operation. The newly designed final focus system [6], which allows a doubling of L^*, would simplify the detector design even further.

One can see that the SLD area, after proper engineering, or a site with similar characteristics, would be compatible with a linear collider having nanometer scale beam sizes.

3 CONCLUSION

Several aspects of ground motion require particular attention, namely studies and modeling of cultural noises and in particular those generated in the detector area of a linear collider. Studies of the cultural noise in the SLAC SLD area presented in this paper will help to determine the engineering requirements of various subsystems of the detector to be compatible with NLC requirements.

We would like to thank G.Bowden and T.Raubenheimer for various useful discussions.

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