INCOHERENT GROUND MOTION

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Abstract

The next generation linear collider should provide a center of mass energy between 500GeV-1TeV with luminosity as high as 1×10^{33} to 1×10^{34} $cm^{-2}sec^{-1}$. One of the most critical parameters is the small vertical beam size at the interaction point, therefore a proper alignment system is necessary to achieve the high luminosity. The vertical tolerance of the accelerating structure is 30 microns but the tolerance of the focusing elements is 1 micron in case of C-band linear collider. The power spectrum density and the coherence function for ground motions are studied for the construction of large scale and high luminosity electron-positron linear collider. We describe recent observed incoherent ground motions and the related methods of cutting the tunnel and forming the basis to reduce the distortion from the ground motions.

1 INTRODUCTION

The luminosity of the linear collider (LC) is given,

$$L = \frac{f_{rep} N^2}{4\pi\sigma_x^*\sigma_y^*} ,$$

where f_{rep} is the repetition rate of collision, N is the number of particles per bunch and, σ_x and σ_y are transverse rms sizes of the beam at the collision point. Since LC has a relatively slow repetition rate, small sizes of the beam should be generated and preserved in the machine to obtain the required high luminosity. One of the most critical parameters is the extremely small vertical size of the beam at the interaction point, therefore, a proper alignment of the focusing and accelerating elements of the machine is necessary to achieve the high luminosity [1]. The small beam size results in severe tolerance requirement for machine components. Incoherent vibration as shown in Fig. 1 would destroy the straight trajectory of the carefully aligned structure and lead to luminosity losses. In addition to the incoherent vibrations, slow drift of the ground occurring like Brownian motion of rocks becomes dominant at frequency region less than 0.1 Hz. In this frequency range, the measured power spectrum density of the ground motion can be characterized by k/f^2. This coefficient k is site dependent parameter. The sources of the slow ground motion are atmospheric activity, change of underground water, ocean tide, temperature variation of the surface ground and so on [2]. But the dominant part of the ground motion at $f < 0.1$ Hz is inelastic motion caused by energy dissipation of the elastic motion such as earth-tide or deep crust movement.

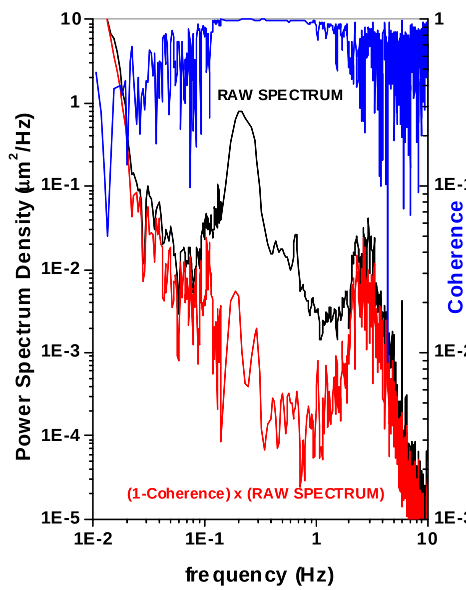

Figure 1: Coherence between two sensors at a distance of 48 m, ground motion spectra of two points and incoherent spectrum observed in KEK tunnel

2 DESCRIPTION OF GROUND MOTION

The slow ground motion shows a random like process in almost all cases, then we can describe the average behaviour in a stationary condition. The power spectrum of the random process $x(t)$ is defined as,

$$P(f) = \lim_{T\to\infty}\frac{1}{T}\left|\int_{-T/2}^{T/2} x(t)\exp(-2\pi ft)\,dt\right|^2 .$$

This power spectrum gives squared dispersion,

$$\sigma^2 = \int_{-\infty}^{+\infty} P(f)\,df = \left\langle x^2(t)\right\rangle = \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} x^2(t)\,dt .$$

Since the power spectrum is real and symmetric signal, it is sufficient to consider only positive frequencies. The correlation between distant measuring points is given by a cross-spectrum,

$$P_{12}(f) = \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} x_1(t)\exp(-2\pi ft)\,dt\int_{-T/2}^{T/2} x_2^*(t)\exp(2\pi ft)\,dt$$

or a normalized cross-spectrum,

$$S_{12}(f) = \frac{P_{12}(f)}{\sqrt{P_1(f)P_2(f)}}.$$

The absolute value of this normalised cross-spectrum is coherence. *ATL* is one of the models describing the diffusive ground motion [3]. Slow relative ground motion is like Brownian motion and the number of discrete breaks appearing between two points is proportional to the distance and the passed time. These discrete breaks consist of random popping up/down of fragmented rocks. The popping motion of the rocks, however, are not complete random phenomena, then the two dimensional covariance function introduces *ATL* model. This model means that the variance of the relative displacement for two points is proportional to their distance *L* and the time interval *T* of observation. That is,

$$\sigma^2 = ATL.$$

The value of *A* should be influenced dominantly by the earth properties.

3 ACTUAL GROUND MOTION

3.1 Artificial noise region

The ground motion in the seismic frequency region usually shows complex power spectrum. The spectrum is composed of smooth spectrum as k/f^n, ocean swell around 0.2 Hz, crustal resonance around 3 Hz and noises of human activity in the frequency range 1 to 100 Hz.

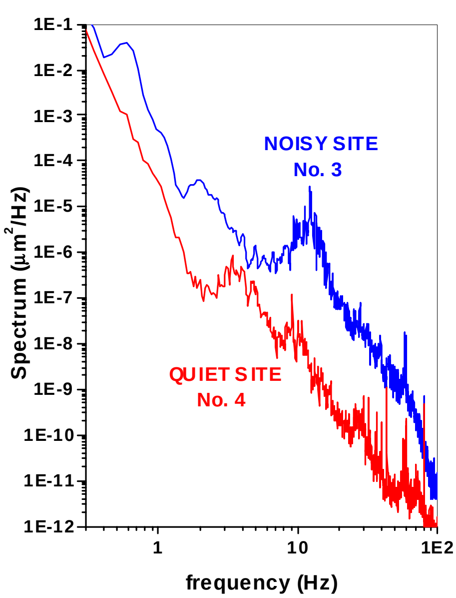

Figure 2: Ground motion in the noisy granite tunnel and the quiet tunnel

Figs. 1 and 2 show broad spectrum bumps around 3 Hz caused by traffic noises. This ground motion is incoherent one, since the different sources are not far from the sensors. Although the tunnel of KEK (TK) and the noisy site in Fig. 2 (TN) have similar distance from the noise sources, their amplitudes are very different and the amplitude ratio becomes about 500:1. TK is in the gravel and clay bed, but TN in the granite. Geological difference must explain this discrepancy of the amplitudes. The amplitude of TN is 6×10^3 times as large as the amplitude in the tunnel of quiet site (TQ), as shown in Fig. 2. TN and TQ are similar granite regions, though the latter is very far from the traffic noise sources (about a few km). These results must suggest that the vibration is similar to the surface wave of the earthquake.

A very large and broad peak around 0.2 Hz in Fig. 1 is not artificial noise but corresponds to very far ocean swell. The long distance from the sources gives good coherence between the two sensors as shown in Fig. 1.

3.2 Slow drift region

Dominant part of the ground motion in the low frequency range (f < 0.1 Hz) is related to the *ATL* model. Although the earth-tides have good correlation on time and space in this frequency range, the residual ground motions consist of diffusive drifting motions. *ATL* model, mentioned in the section 2, well describes this observed residual ground motions. The value of *A* depends on the ground properties or fragmentation of the rocks [1, 2]. Typical values of *A* studied in Japan are given in Table 1. Although the amplitude ratio of TK to TN, as mentioned above, is very large, *A* is not so different from one another as shown in Table 1, No. 1 and No. 3 respectively.

Table 1: ATL coefficient in Japan

No	Site Name	A (nm^2/m/sec)
1	Tunnel of KEKB	4.0E+01
2	Rokkoh-1	3.6E+01
3	Rokkoh-2	3.3E+01
4	Miyazaki	1.5E+01
5	Kamaishi-1	1.4E-01
6	Kamaishi-2	5.7E-02
7	Sazare	5.0E-02
8	Esashi-1	5.7E-03
9	Esashi-2	2.0E-03

We have to investigate carefully on the orbit stability and emittance dilution caused by *A* [1], as well as on the initial alignment of the accelerating components. A beam-based alignment technique for correction of accelerating structure is available, after we once get to use the beam. However, We should pay attention to the initial alignment without beam. *ATL* coefficient of 1 nm^2/sec/m, for example, indicates that we must align the 30 km machine within 100 days providing the accuracy better than 0.5 mm. There are three sets of the same site name in Table 1. The values of *A* are not so different in each group. The coherence, however, shows very different frequency dependence as described in the next section.

4 COHERENCE

4.1 Effect of the fault

Fig. 3 shows the coherence observed in the granite tunnel. We set one of the two sensors at the fixed point, and the other was set at a distance of 60 m spanning over the fault (No. 2) or not spanning over the fault (No. 3). No. 2 rapidly decrease its amplitude in the frequency range higher than 0.3 Hz, in contrast to the amplitude for No. 3 being almost flat up to 10 Hz. The amplitude of No. 2 is about 0.85 in the frequency range lower than 0.3 Hz. As a result, we can say that the fault is one factor of the incoherent ground motion in the seismic frequency region (0.1 Hz $<f<$ 30 Hz). The *ATL* coefficient in the low frequency range, however, gives only a little difference as shown in Table 1, which may reflect the coherency.

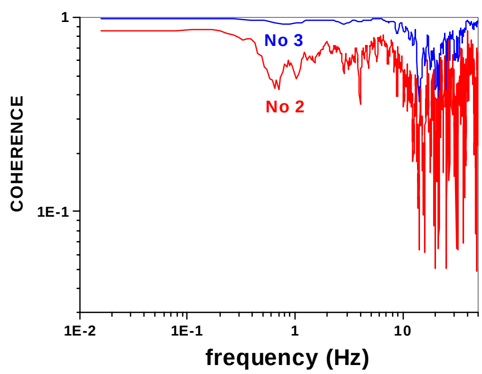

Figure 3: Coherence in the granite tunnel corresponding to the noisy site in Fig. 2, No 2 and No3 in Table 1

4.2 Effect of blasting crevice

Takeda et al gave the difference of coherence between the smooth blasting method (SBM) and TBM using the observed data [2]. An aftereffect of these two excavating methods was shown as distinct difference of the coherence at near the betatron wave-length of LC. SBM induces quite a size of relaxation in the surface layer (about 1m or more). We concluded that excavation using TBM in the hard rock is essential for LC in order to eliminate overbreak on the surface of the tunnel [1, 2].

We executed several experiments to get more detailed information about the surface layer of the granite tunnel cut by SBM. The first result was shown at IWAA'99 [4]. We set three sensors at intervals of 17 meters. No. 5 and No. 6 in Table 1 correspond to the both ends of sensors. The coherence between the middle sensor and the both ends shows very complex daily changes at the frequency range less than 10^{-2} Hz [4]. We speculated that the daily fluctuation is caused by the activity of underground water. In order to check this speculation, we built a dam across the flow to control the water level in the crevice. As a result of this experiment, Fig. 4 shows flat coherence in the wide frequency range, though No. 5 gives a little bad coherence (about 0.8 on the average).

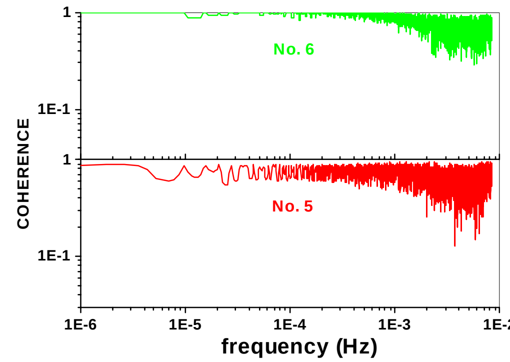

Figure 4: Wide band coherency obtained by artificial control of the water level

We have a new plan to construct the tunnel for C-band LC, following our detailed study on the excavation. From the view point of *ATL* and the coherency the separated tunnel as shown in Fig. 5 is preferable to suppress the noises in the accelerator tunnel caused by the accelerator facility. As mentioned above, we have to pay attention to the local fluctuation of *ATL* coefficient and the coherence for long scale LC. The present results show that there would be a significant change of coherency within the betatron wave length (about 30 m for C-band LC). Then we are now proceeding a new supporting system for the accelerator components in order to compensate the ground motion.

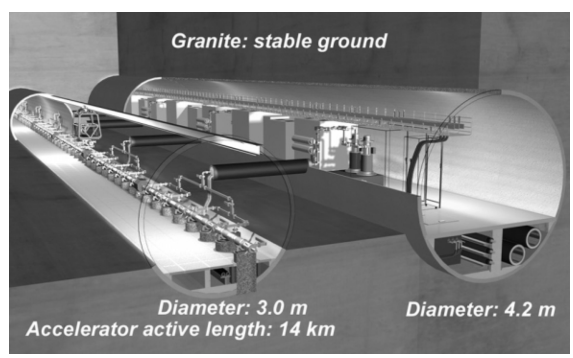

Figure 5: Schematic description of C-band linear collider

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