SLOW GROUND MOTION AND LARGE FUTURE ACCELERATOR

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1 INTRODUCTION

The power spectrum density of the ground motion is studied for the construction of large scale and high luminosity machines[1]. Although the tolerance for errors of the linear collider strongly depends on the design of the machine, they require severe tolerance for the machine components. The natural level of seismic vibrations has been usually considered as seriously affecting machine operation. They are assuming that slow ground motion much less than characteristic frequency of an accelerator gives complete space and time coherence of the machine displacements. Our experimental results, however, suggest being frequency dependent structure for the space coherence in the low frequency range[2]. A long term drift and slow fluctuations of the ground motion were studied on the different crustal structure to get the detailed power spectrum density and space coherence[3,4]. We use a water-tube-tiltmeter for the spectrum below 1 mHz and a broadband seismometer to get the spectrum from 10 mHz to 100 Hz. Both power spectra is interpolated using the electronic bubble level. This paper gives some detailed discussions about the relation between the linear collider and ground motion using the observed data.

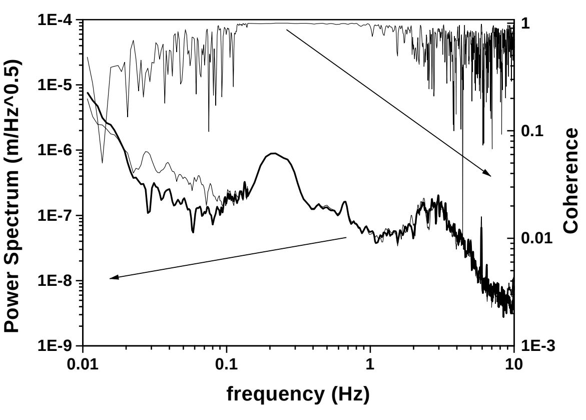

Figure 1: A typical example of the ground vibration in KEK. The spectra were observed by two seismometers at a distance of 48 meters.

2 COHERENCE

2.1 Clay Layer

The accelerator tunnels in KEK constructed under the surface of the earth are influenced easily by the ground motion. The tunnel is enclosed in the clay layer or stands on the clay. To prevent the body of tunnel being damaged by the stress of the ground motion, so-called expansion joint is installed everywhere of the tunnel. Takeda et al. observed coherence of the ground vibration in the tunnel with expansion joint as a function of the distance of measuring points[2]. Figure 1 is a typical example of the ground vibration measured with two seismometers set up 48 meters apart in KEK. There is no difference between the two spectra. On the contrary of this evidence, the correlation between two seismometers becomes bad except the frequency range 0.1 to 1 Hz.

There are two broad bumps in Figure 1. The bump around 0.2 Hz corresponds to the ocean swell. On the other hand, the bump of about 3 Hz is a crustal resonance of the earth caused by human activity in the vicinity of KEK[2,4]. It can be said to the vibration from the adjoining source that coherence is lost though there is good coherence in the vibration from the great distance. Then, we should consider about the cause coming out from incoherence of 0.1 Hz or less. In this frequency region, the power spectrum density, as a function of frequency f, is inversely proportional to f^2 except coherent peaks of the earth tides[3,4]. This frequency dependence of the spectrum is similar to Brownian motion with the fractal dimension D=1.5[5].

We have observed a block movement of the tunnel with expansion joints. Two electronic bubble levels were set side by side (separated by 50 cm). Figure 2 shows a result for the same tunnel block, and Figure 3 a result for the different tunnel block separated by an expansion joint. There is visible difference between them. This experimental result shows that there is a frequency region where the adjoined tunnel block moves independently. This experimental result suggests that similar phenomena can be observed on the real ground motion around the discontiinuity of the rock mass.

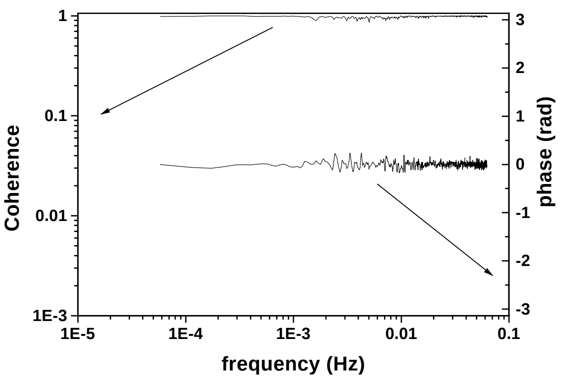

Figure 2: Coherence and phase difference between two sensors separated by 50 cm with no expansion joint.

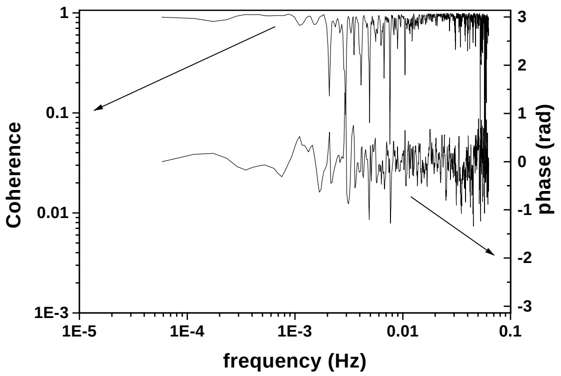

Figure 3: Coherence and phase difference between two sensors separated by 50 cm with an expansion joint.

2.2 *Hard Rock*

In order to compare the difference of geological property, we have also studied in the tunnels of welded tuff and granite using the same electronic bubble levels. The physical property of each rock is almost the same (for instance, V_s is about 3 km/sec). There is a difference, however, in the construction method of the tunnel. The tunnel of welded tuff was dug using dynamite (NATM) and the tunnel of granite using a drilling machine. The experimental results are shown in Figures 4 and 5. The Figures show the results for two levels separated by a distance 46 m.

The followings are found out comparing Figure 4 with Figure 5:

- The coherence decreases in the frequency range of $5*10^{-4}$ Hz or more in Figure 4, on the other hand, Figure 5 shows good coherence for almost all frequency range of the present observation.
- The phase relation has a big difference between them. In Figure 4, the phase changes in the whole frequency range and it becomes at random in the frequency range of $3*10^{-3}$ Hz or more, though it is almost stable in Figure 5. It is out of phase in the low frequency range of Figure 4.

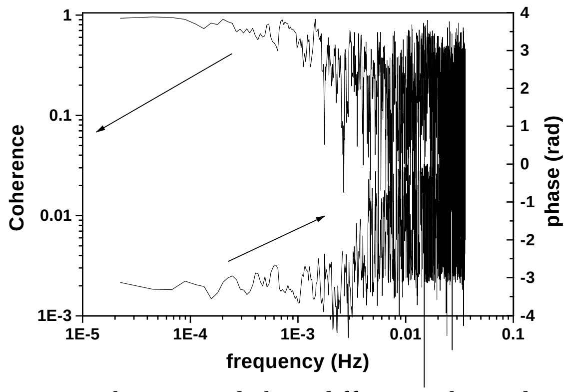

Figure 4: Coherence and phase difference obtained in the welded tuff tunnel. Two levels were set up 46 meters apart.

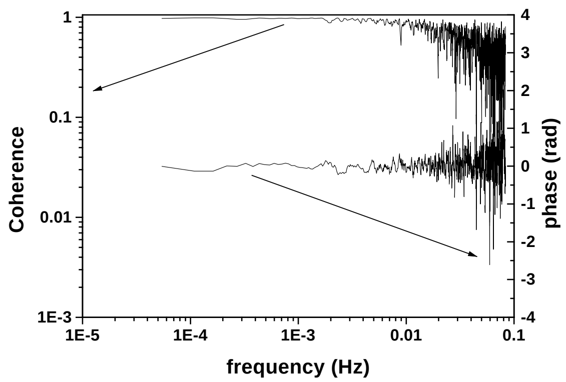

Figure 5: Coherence and phase difference obtained in the granite tunnel. Two levels were set up 46 meters apart.

We can say by the experimental results concerning the coherence as follows:

- The tunnel is divided into the block and our obtaining result is information on the movement of the block.
- The size of the block depends on the method of digging the tunnel and/or geological property.

3 SPECTRUM

The power spectral density of the ground motion is described by a simple and empirical power law equation, though the seismic motion in the frequency band from 0.01 to 100 Hz. In the frequency range 0.01 Hz or less, the spectrum can be roughly characterized by k/f^2 [3,4]. The coefficient k is related to the geological property and it changes from 10^{-18} m^2/Hz to $3*10^{-16}$ m^2/Hz.

Figure 6 shows the power spectral density for the tunnel of welded tuff in connection with Figure 4. The spectrum is also inversely proportional to f^2. The coefficient *k* is about 10^{-17} m^2/Hz. Figure 7 shows the power spectral density for the tunnel of granite in connection with Figure 5. In this case, the coefficient *k* is about $2*10^{-18}$ m^2/Hz. This k value is almost the same as the value obtained at Sazare[3,4]. In physical properties, there is no big difference between the rock of Sazare and welded tuff. However, k value obtained from Figure 6 is five times as large as the value from Figure7.

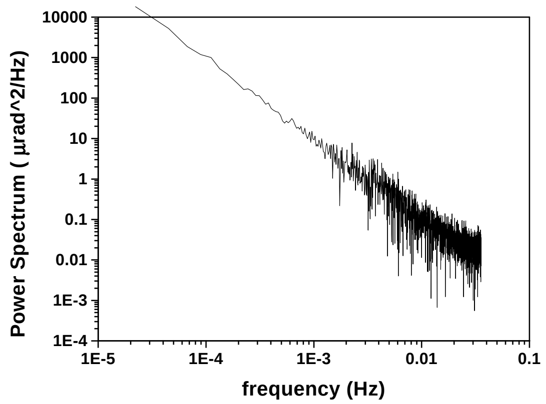

Figure 6: Power spectral density obtained in the welded tuff-tunnel.

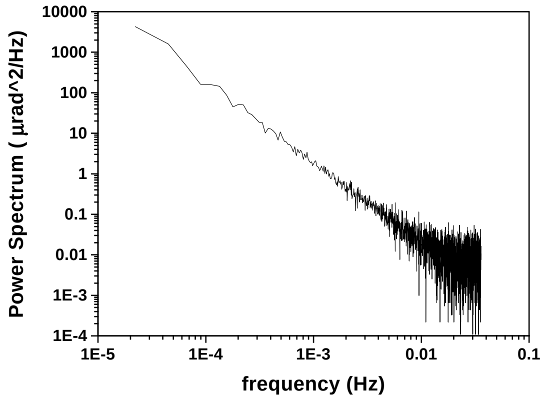

Figure 7: Spectral density obtained in the granite tunnel.

The tunnel of Sazare was dug using the drilling machine. From these experimental results, we can say that the basic rock has many subdivided rocks where the tunnel was dug using dynamite, and fragmented rocks move randomly like Brownian motion.

4 CONCLUDING REMARKS

New electron-positron linear colliders considered for the future should provide a center of mass energy in the range of 500 GeV-1 TeV with luminosity as high as 10^{33} to 10^{34} $cm^{-2}sec^{-1}$[6]. Since the linear collider has a relatively slow repetition rate, large number of particles and small sizes 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. The small beam size results in severe tolerance requirement for machine components. The ground motion would destroy the straight trajectory of the carefully aligned structure and lead to luminosity losses. This is the motivation for study of the ground motion.

We are now able to obtain the information of the ground motion for various sites[1]. Sery and Napoly gave a modelling method of the ground motion to calculate the behavior of beams in the linear collider[7]. All most all data, however, are concerning power spectral density and its frequency range is 0.01-100 Hz. We have observed power specrum and coherence as a function of distance for lower frequency range. The experimental results are as following:

- There is a place where the spectra are very like but the coherence changes largely.
- Coherence is more sensitive to the digging method than spectrum.
- There is a band structure in the observed coherence.

And the results suggest:

- We have to select the site not only refering small amplitude of the spectrum but also the coherence in a distance longer than the betatron wave length.
- When we construct the tunnel, we should avoid the digging method to crush the basic rock mass.
- We should design the machine of as large tolerance as possible since the culture noise originated by itself is incoherent.

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