INVESTIGATION OF SEISMIC VIBRATIONS AND RELATIVE DISPLACEMENTS OF LINEAR COLLIDER VLEPP ELEMENTS

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Abstract

In this work the results of seismic motion measurements in the Protvino region where VLEPP and UNK will be build are presented. Measurements of correlations and power spectrums were carried out in UNK tunnel and on the Earth surface. Factors that give main contributions to seismic motion had been investigated. Significant influence of atmospheric pressure on low frequency seismic motion was observed. This work is important for linear supercollider VLEPP design.

1. Introduction

Linear electron-positron supercolliders need very small beam transverse sizes for high luminosity [1]. For example, for luminosity of VLEPP about $10^{34}\text{cm}^{-2}\text{s}^{-1}$ beam sizes in the interaction point should be 3*0.001 microns, and for project JLC - 0.23*0.0014 microns [2]. Precise alignment of focusing elements needs in this case. Estimations show that appreciable lens displacement from beam line is about 0.03 microns for main linac and 0.001 microns for final focus system.

During the collider run magnetic axis of lenses should be tune by feedback system working from beam position monitors. Vibro- and seismic noise levels, it's correlation properties are very important for vibration suppression system designing.

In this work the results of seismic motion measurements in the Protvino region, where VLEPP and UNK supercolliders will be build, are presented. Measurements of correlations and power spectrums were carried out in the UNK tunnel. Measurements of absolute and relative Earth surface motions, influence of atmospheric pressure on low frequency ground vibrations were carried out inside lab building. Details of this measurements could be found in INP Preprints [3,4,5].

2. Methods and instruments

Underground measurement point was situated 3 km to North from U-70 accelerator in UNK tunnel on the depth of about 30 m. Tunnel ground motion were measured in three directions by industrial seismometers SM-3KV. These probes were calibrated in the frequency range of 0.03-100 Hz. 12 bit CAMAC ADC with 700 and 80 Hz toggle frequency was used for digitizing of signals . In correlation measurements information from three probes placed at different points was simultaneously stored in CAMAC memory. For these measurements we choose probes with similar phase characteristics. Maximum distance between probes in pair correlation analysis was 140 m.

Surface measurements were made in lab building where four massive tables for VLEPP accelerating structure were installed. For absolute table vibration measurements in frequency range of 0.003-2 Hz we used seismometer SVK-D with atmospheric pressure compensation. The probe was placed on one of the tables. To measure relative movements of different tables we used tungsten wire with diameter 28 microns and length up to 14 m passing through pick-ups [3]. The wire was strained by stable force of 1.4 N independent of air temperature variations. Sensitivity of the probe is 10 mV/microns, one quantum of 20 bit CAMAC ADC was equal 1.0 microVolt (10^{-4} microns)

3. Results of measurements

Power spectrum of vertical seismic vibrations in the UNK tunnel is shown at fig.1. These measurements were done in quiet conditions (evening of saturday).

One can see wide peak near 0.14 Hz, so called "7 second hum". The origin of this peak is usually connected with water and atmospheric activity above the ocean results in seismic waves in an earth [6]. Measurements show also that in quiet conditions vertical and horizontal spectrums are approximately equal.

Our measurements have shown that displacement due to microseismic peak does not depend on technical activity in the place of measurements. Technical noises manifest itself mainly at frequencies above 1 Hz. At weekday power spectrum at these frequencies increases more than one order of magnitude.

At frequencies greater than 10 Hz the influence of traffic activity is clearly seen. For example heavy car moving with velocity 40 km/h along the road placed of 70 m aside of measurement point results in increasing of displacements up to $(6\text{-}10)*10^{-4}$ microns, i.e. 2-3 times higher than in quiet conditions.

One can also see at fig. 1 spectrum of relative movement of two VLEPP tables measured by strained wire technique. The value of relative displacements is considerably less than absolute ground motion at frequencies below 1 Hz. At higher frequencies both spectrums are the same due to local character of vibration sources.

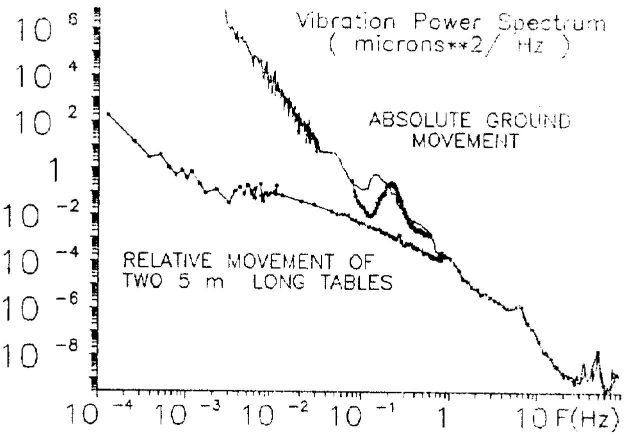

Fig.1 Power spectrums of UNK tunnel ground vibration and relative movement of two VLEPP tables

Correlation spectrums of vertical motion for distances between probes equal to 40 and 140 m are shown at fig.2 . Correlation spectrum of two signals $X(t)$ and $Y(t)$ is equal to real part of expression:

$$K(w)=\frac{<X(w)*Y^{*}(w)>}{(<|X(w)|^{2}>*<|Y(w)|^{2}>)^{1/2}} \qquad (1)$$

One can see that frequency region of high correlation decreases with increasing of distance between probes. It is also seen that for long distances high correlation exists only near the frequency of microseismic peak. The source of these peak is remote (few thousands of kilometers) and very powerful . So the correlation of two probes should be equal to unit multiplying by factor that depends on phase delay between them.

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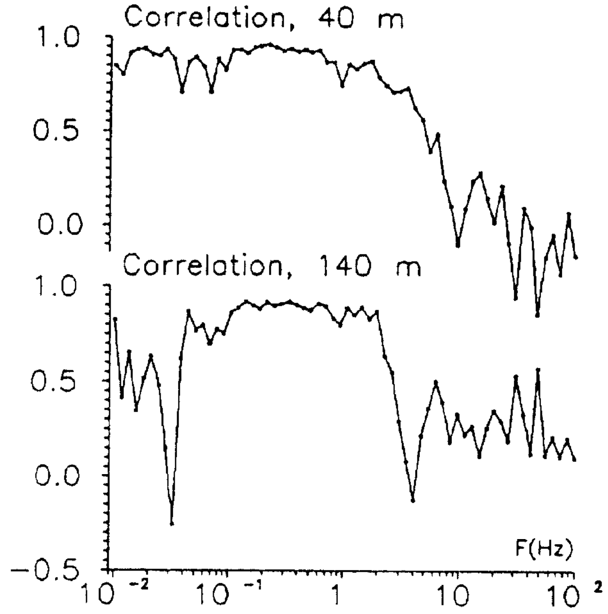

Fig.2 Spectrum of correlation for two distanced probes

4. Influence of atmospheric activity on Earth surface motion

A. Measurements

Influence of atmospheric activity on Earth motion was studying in the lab building. Absolute motion of surface, atmospheric pressure, temperature and relative displacement of VLEPP tables were measured simultaneously. Maximum distance for relative measurements was 14 m.

These measurements confirm great influence of atmospheric pressure variations on surface motions at frequencies less then 0.2-0.3 Hz. The influence can have remote or local character.

Seismic motion in the range 0.06-0.25 Hz due to "7 second hum" is an example of remote influence. In this frequency range power spectrum usually has a peak on mean frequency 0.14 Hz (fig.1). The mean frequency, shape and amplitude of peak depends on weather condition above ocean. Amplitude of peak can vary from 0.1 to 10 $\text{microns}^2/\text{Hz}$. As a rule, bigger amplitude corresponds to lower mean frequency. The mean frequency of microseismic peak f can be determined from equality of mean wind velocity V to phase velocity of gravitation waves on ocean surface: $f=g/(2*\pi*V)$, where g- is the acceleration of gravity. Then for the mean frequency f=0.14 Hz we get reasonable value of wind velocity V=11 m/sec.

Local changings of atmospheric pressure and temperature influence also on motions at frequencies lower than 0.1 Hz. So we observed relative vertical displacement of two VLEPP tables equal to 30 microns during storm coming with rapid pressure changing about 15mm Hg (see fig.3).

Significant variations in atmospheric pressure result in clearly seen correlation between pressure and Earth surface motion (fig.4). The correlation has a leap due to mechanical resonance of seismometer at 0.08 Hz.

Therefore, the main contribution to ground motion in frequency region of 0.01-0.1 Hz is due to atmospheric pressure fluctuations.

B. Model of atmosphere influence on ground motion

Atmospheric flows (i.e. winds) usually have high number of Reinolds (about 10^6 and more) and high power of turbulence. For developed turbulence Kolmogorov-Obukhov law [7] gives a connection between fluctuations of flow velocity V for flow regions with sizes about λ:

$$V \simeq U*(\lambda/L)^{1/3} \qquad (2)$$

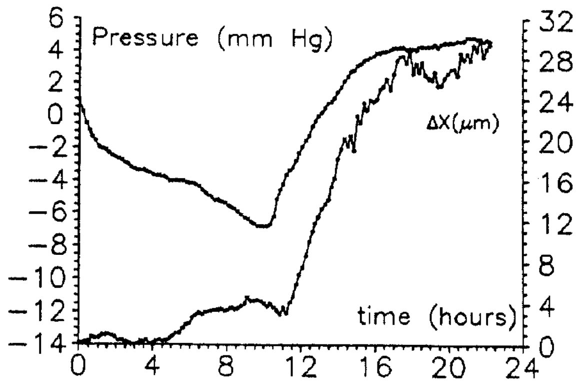

Fig.3 Pressure and relative vertical movement of two tables during cyclone passing through Protvino region at 26 of January 1991.

here U,L - main flow average velocity and size, in our case average wind velocity and thickness of atmosphere. For every size λ one can find frequency of fluctuations of flow parameters in some point of measurements:

$$f \simeq U/\lambda \quad , \qquad (3)$$

and then

$$V_\lambda = V_f \simeq U^{4/3}*(f*L)^{-1/3}. \qquad (4)$$

One can estimate fluctuations of pressure:

$$P_f \simeq \rho*V_f^2/2 = \rho*U^{8/3}*(\ f*L\ )^{-2/3}/2 \qquad (5)$$

(ρ - air density) and spectrum of this fluctuations:

$$\mathbf{S}(P)_f \simeq \frac{P_f^2}{f} = \rho^2*U^{16/3}*L^{-4/3}*f^{-7/3}/4 \qquad (6)$$

Fig.5 shows good agreement of formula (6) at L=5000 m and U=3 m/sec with measured power spectrum of atmospheric pressure fluctuations.

One can estimate absolute ground displacement X_f under the force of atmosphere pressure P_f regarding a ground as elastic homogeneous isotropic bounded medium with Youngs modulus E_f:

$$X_f \simeq P_f*\lambda\ /E_f = \frac{P_f*U}{E_f*f} \qquad (7)$$

Therefore, spectrum of power:

$$\mathbf{S}(X)_f \simeq \rho^2*U^{22/3}*E_f^{-2}*L^{-4/3}*f^{-13/3}/4 \qquad (8)$$

Results of spectrum calculations according to (8) with $E=10^8\ N/m^2$ are shown in fig. 5 in comparison with experimentally measured ground vibration spectrum. For infralow frequencies more reasonable consider a ground as a liquid with density ρ. In this case ground motion

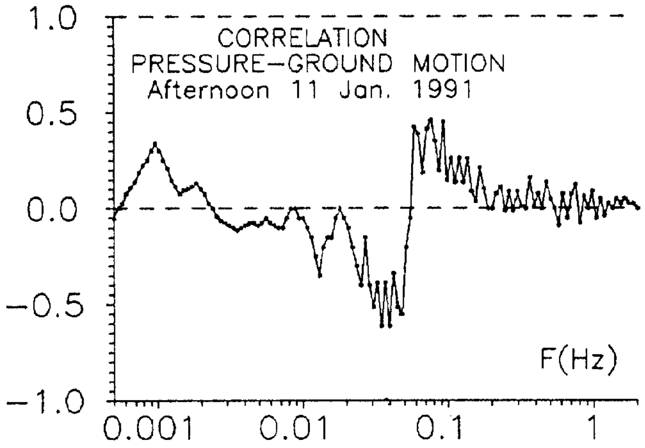

Fig. 4 Correlation between pressure and ground motion.

is frequency independent :

$$X_f \simeq P_f/(\rho*g) \qquad (9)$$

Transition from solid to liquid model corresponds to sizes :

$$\lambda_{max}/E \simeq 1/(\ \rho*g\ ) \qquad (10)$$

If $E=10^8$ N/m^2 then $\lambda_{max} \simeq 3000$ m and $f_{min} \simeq 10^{-3}$Hz. In the liquid model atmospheric pressure variations of 10 mm Hg leads to maximum ground displacement of about 4 cm.

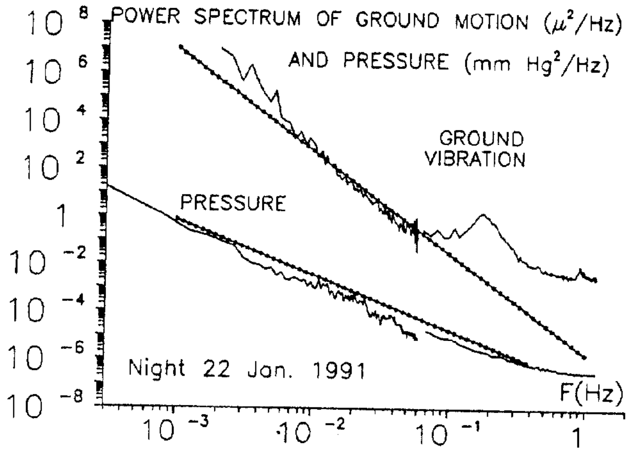

Fig.5 Comparison of vibrations and pressure spectrums with model (see text).

5. Low frequency Earth surface movements

Besides the oscillating type of motion considered above earth surface has another one like diffusion due to tension drops inside the bulk. Random character of that jumps leads to continuous diffusion of all surface.

Suggesting that the jumps probability is proportional to distance between points of surface L and time t one can make estimation of relative displacement dispersion for two points (here A - parameter of the model) :

$$< x^2 > = A*t*L \qquad (11)$$

Results of our measurements of ground displacements using strained wire and of optical measurements in the UNK region of another group are in good agreement with the model with parameter $A=10^{-4}$microns^2/(sec*m). 17 year studies in Stanford Linear Collider tunnel [8] show maximum vertical displacements were 15 mm and horizontal 7.5 mm and it gives $A=1.4-0.4*10^{-4}$ microns^2/(sec*m). Good agreement of data from different places points to the general character of ground motions.

Using this model one can predict displacements of the center of 20 km long VLEPP tunnel after different time (see Table 1).

Table 1

1 sec	1 min	1 hour	1 day	1 month	1 year	10 year
1.4 μm	11μm	84μm	415μm	2.3mm	7.7mm	24 mm

These displacements determine dispersions and main parameters of collider alignment feedback system.

Conclusion

In conclusion we should say that:

1. Power spectrum of seismic motion falls fast with increasing of frequency. So if there will not be strong technical sources of vibration it allows to neglect vibrations with frequency greater than 10 Hz, which amplitude is less than 0.001 microns.

Increasing of r.m.s. size of beam in interaction point due to vibrations at these frequencies :

$$\Delta X^2{}_f = \Delta X_0^2 * \sum_i^N \frac{\gamma_i * \beta_f}{\gamma_f * \beta_i} \simeq \Delta X_0^2 * \frac{N}{2} * \frac{\beta_f}{\beta_i}$$

where $\gamma=E/mc^2$, β_i and β_f beta-function in lens with number i and in interaction point. If $\beta_i = 5$ m, $\beta_f = 1$ mm, $N = 10^4$, then r.m.s. size would be about 0.001 microns.

2. Amplitude of motions in region 0.1 - 1 Hz is about 1 microns, and in region 1 - 10 Hz - up to 0.01 microns. These values determine requirements on speed and accuracy of feedback systems. High correlation in this case can make the requirements weaker.

3. Motions with frequencies less than 0.1 Hz determine working range of slow alignment systems. For a time of about one hour displacement can achieve 80 microns, for one year - as much as 7 mm. It means that the range of slow alignment system must be a few mm with accuracy a few microns. In this case slow alignment system would fit to the range of fast feedback.

4. It is clearly that any technical sources of vibration (highways, compressors, ventilators, etc.) should be placed far enough from the collider if possible. Another way is to suppress the vibrations from this source at the points of their creation.

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