Measurements of the Ground MotionVibrations at the SSC

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Abstract

The results of seismic ground measurements at the Superconducting Super Collider (SSC) Accelerator Systems String Test (ASST) site are presented. Spectral analysis of the data obtained in a large frequency band from 0.05 Hz to 2000 Hz was performed.

I. INTRODUCTION

Vibration effects on collider performance have been theoretically studied in several works [1,2,3,4]. Depending on the frequency of the noise, one can distinguish two mechanisms of beam perturbation. At low frequencies (much less than revolution frequency), the noise produces a distortion of the closed orbit of the beam. The acceptable level of uncorrelated low frequency motion of any single SSC quadrupole is about 0.1–0.3 micrometers [2]. Narrow band high frequency noise centered near a fractional part of the betatron frequency causes direct emittance growth. Depending upon the final value of the fractal part of the tune of the SSC (0.2–0.4) this band center will be located in a frequency range between 700–1200 Hz). For example, high frequency turn-to-turn jitter of every quad with an amplitude about 10^{-4} micrometer will cause emittance doubling after only 20 hours, see Reference [4]. Experimental investigation of underground vibrations at the SSC site at frequencies 1–200 Hz was performed by The Earth Technology Corporation (Long Beach , CA.) in 1989 [5]. At the time of that study the main concern was with the low frequency closed orbit distortion. Since that time, however, there has been a growing interest in the higher frequency emittance growth issue. This paper present results of recently conducted seismic ground motion measurements at the ASST (located at the N-15 SSC site) in the frequency range from 0.05–2000 Hz.

II. EXPERIMENTAL

Two types of seismic probes were used in the study. The first was a commercially available model SM-3KV velocity meter which was modified to accommodate a frequency range from 0.05–150 Hz. Two of these probes were used in the study and both have a nominal sensitivity of 8×10^4 Volt/m/sec and were calibrated for use in the vertical direction. The second type of probe was a model TA-2 accelerator produced by the Moscow Institute of Earth Physics. Again, two such probes were used in the study and both had a nominal sensitivity of 0.5 Volt/m/sec^2 in the vertical direction. The dynamic range of these probes (over the frequency band10–2000 Hz) is 100 dB relative to the acceleration of gravity. Signals from all probes were digitized simultaneously by CAMAC 10-bit ADCs (with a variable sampling frequency up to 32 kHz) and then sent to CAMAC 256 K memory for storing. The maximum memory available for one channel was 64 K 24-bit words. This corresponds to 17.8 hours of permanent measurement time with a sampling rate 1 Hz or about 1 minute with 1 kHz. For long measurements a low pass filter at either 2 Hz or 20 Hz was used; for fast analyses 2000 Hz and 10 000 Hz band filters were applied.

The data was later transferred from the CAMAC memories to an IBM PC/386 for subsequent processing in both the time and frequency domains. The analysis basically consisted of 1) convert the raw data signals from voltage to vibration amplitudes in microns, 2) compute the discrete Fourier transform of the converted signals, 3) calculate the power spectral density (PSD) of the signals, and 4) calculate the spectral correlation between all signal pairs, etc.. In performing the spectral analysis 64 averages were used to reduce the signal noise and statistical errors in the data. The spectral correlation of two signals x(t) and y(t) is defined as

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

where *X(w)* and *Y(w)* denote the Fourier transforms of *x(t)* and *y(t)* respectively. The brackets in the above expression denote the averaging process over the 64 measurements.

III. RESULTS

The PSD of the ground motion at the SSC site in quiet conditions is shown in Figure 1 (lower curve). This type of data was collected on the slab of the ASST building during the evenings and over weekends when the construction and installation activity were at a minimum. In this figure we see the microseismic peak located at 0.1–0.2 Hz which is the so-called "seven second hum." We note that the actual location of this peak is not necessarily equal to 0.143 Hz (1/7sec) but instead may vary from 0.07 to 0.25 Hz. It may also consist of multiple peaks [6]. The origin of the "seven second hum" is normally associated with ocean waves of the nearest seas (in the case of the SSC – the Gulf of Mexico and the Atlantic Ocean). Consequently, one would expect the amplitude of this peak to change significantly with time and weather conditions. This fact has been verified by filtering all

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frequency components above 1.0 Hz from the signal and then calculating the rms value of the resulting ground motion signal. This operation was performed on recorded data spanning a three-week observation period from March 2 to March 20, 1993. The result of this analysis is shown in Figure 2. As can be seen, the amplitude of the rms ground motion varies by an order of magnitude from 0.2 to 2.0 microns. The behavior of this value is well correlated with the weather conditions in Florida and over the Atlantic Ocean at the time. Also, sharp peaks on March 5 coincided with small earthquakes. During these earthquakes the amplitude of the seismic motion at a frequency of approximately 0.05Hz (below the 7 second hum peak) was about 100 microns. The motion from each quake lasted for about an hour.

A second probe was located on the coldmass of a dipole magnet which was resting alone on the support stand at room temperature waiting to be installed in the ASST string. The data taken using this probe was during the day under "noisy" conditions. The resulting PSD function is shown as the upper plot in Figure 1. The dashed line of Figure 1 represents an acceptable level for the 0.1 of beam size beam-beam separation at the interaction point of the SSC due to closed orbit distortions caused by quadrupole motion and emittance growth limitation according to Reference [4]. As can be seen from the figure, the vibrational motion at all frequencies increased. Also, resonant frequencies of the coldmass above 10 Hz become evident. This exercise serves to point out that such resonances must be taken into account when calculating vibrational motion limits for the Collider components. It must be carefully noted that the measurements presented here are for a dipole magnet and the vibrational studies noted in the introduction apply to quadrupole magnets. Preliminary analytical studies indicate that there are no quadrupole coldmass resonant frequencies located within the frequency range of 700–1200 Hz where the emittance growth problem manifests itself. These analytical predictions will soon be examined and evaluated by experimental measurements taken on a quadrupole magnet. Both PSD functions shown in Figure 1 indicate significantly high ground motions below 0.1 Hz. However, the corresponding ground wavelength at these frequencies is on the order of 25 Kilometers which does not present a serious danger to the operation of the machine.

Figure 3 presents real (solid curve) and imaginary (dashed curve) parts of the spectral correlation between two SM-3 KV probes placed a distance of 130 meters apart. As can be seen from this figure there is solid positive correlation in a band around the seven second hum frequency. There is also some correlation (0.5) at frequencies between 1.0–2.0 Hz. However, no other significant correlation was observed over the remaining portion of the spectrum. The decreasing of correlation below 0.1 Hz leads to the need for the underground experiments at the tunnel for careful estimation of the influence of this part of the spectrum on the closed orbit distortion.

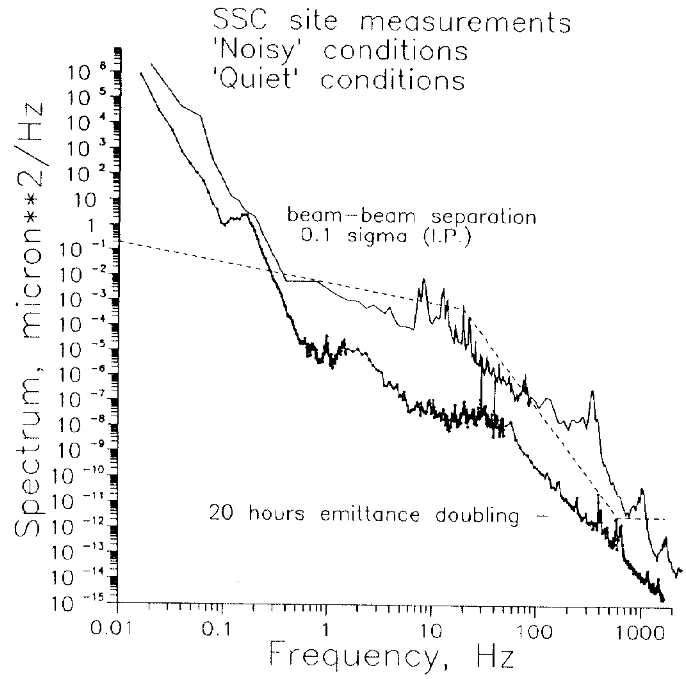

Figure 1. Measured spectra of the ground motion in noisy and quiet conditions.

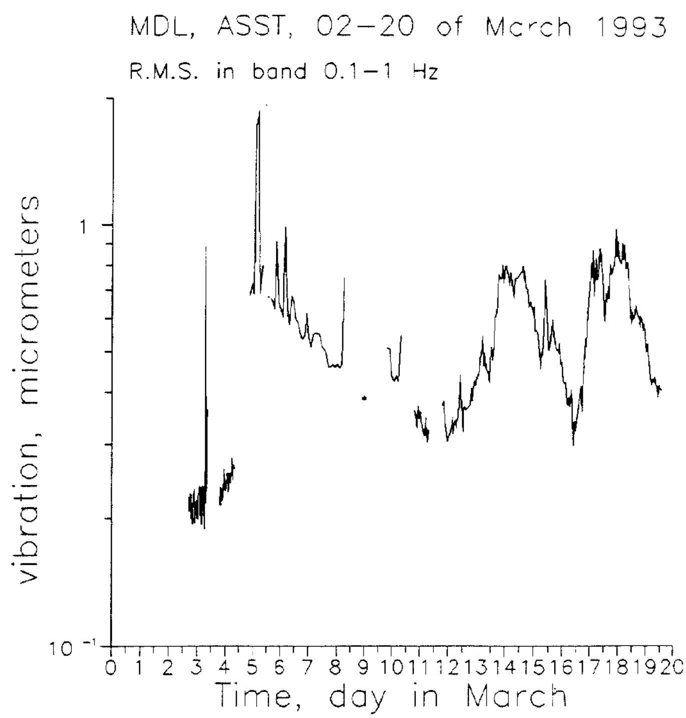

Figure 2. Three week observation of low frequency ground motion.

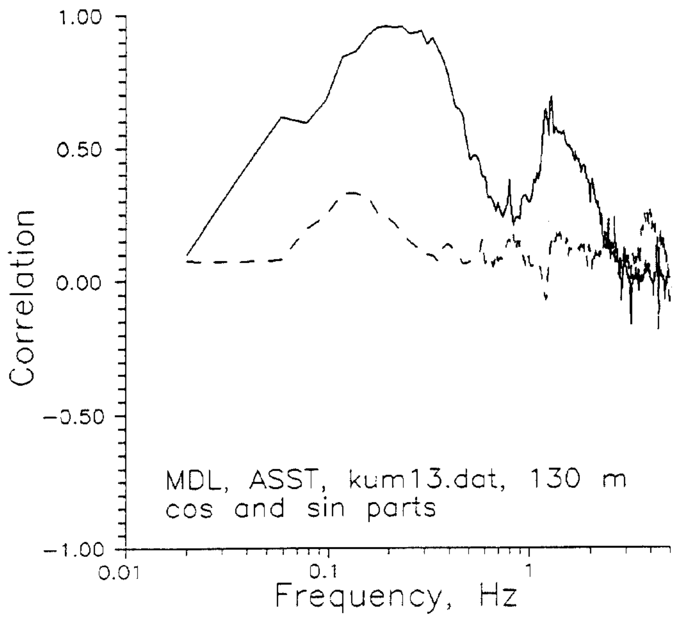

Figure 3. Spectal correlation of ground motion at a distance of 130 meters.

IV. SUMMARY AND FURTHER DEVELOPMENT OF EXPERIMENTS

Seismic ground measurements at the SSC site (ASST building) were carried out during March 1993. The equipment used allowed us to obtain data in a very large frequency band from 0.05 Hz to 2000 Hz.

It was found that at high frequencies (above 10 Hz) the main source of vibration is human activity. Analysis shows that under very quiet conditions, ground motion vibrations at high frequency are not dangerous for the SSC transverse emittance growth. Nevertheless, measurements made under noisy conditions show that resonant frequencies of the quadrupole magnet and support stand, if not properly engineered, could lead to fast emittance growth. The measurements in this paper were performed on the surface at the ASST facility and as a result were quite sensitive to various cultural noise. The next set of measurements will be made underground at the bottom of the exploratory shaft and the sensitivity of ground motion to surface activity examined. It is also planned to experimentally measure the resonant frequencies of the quadrupole magnets to verify the analytical predictions that they are outside of the fast emittance growth danger region.

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V. REFERENCES

[1] G. E. Fischer and P. Morton "Ground Motion Tolerances for the SSC," SSC-55, 1986.

[2] K. Y. Ng and J. O. Peterson "Ground Motion Effects on the SSC," SSC-212, 1989.

[3] V. A. Lebedev, V. V. Parkhomchuk, V. D. Shiltsev and A. N. Skrinsky "Suppression of Emittance Growth Caused by Mechanical Vibrations of Magnetic Elements in Presence of Beam-Beam Effects in the SSC," Preprint-INP 91-120, Novosibirsk, 1991.

[4] V. A. Lebedev, V. V. Parkhomchuk, V. D. Shiltsev and G. V. Stupakov "Emittance Growth due to Noise and Its Suppression with the Feedback System in Large Hadron Colliders," SSCL-Preprint-188, 1993.

[5] The Earth Technology Corporation (Long Beach, CA)., "Field Measurements and Analyses of Underground Vibrations at the SSC Site," Report No. SSC-SR-1043, Dec. 1989.

[6] B. A. Baklakov, P.K. Lebedev, V. V. Parkhomchuk, A. A. Sery, V. D. Shiltsev, and A. I. Sleptsov "Investigation of Seismic Vibrations and Relative Displacement of Linear Collider VLEPP Elements," Proc. of 1991 IEEE Part. Accel. Conf., San Francisco, USA, p. 3273, May 1991.