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GROUND VIBRATION AND COHERENCE LENGTH MEASUREMENTS FOR THE CLIC NANO-STABILIZATION STUDIES

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Abstract

The demanding nanometre transverse beam sizes and emittances in future linear accelerators result in stringent alignment and nanometre vibration stability requirements. For more than two decades, ground vibration measurements were made by different teams for feasibility studies of linear accelerators. Recent measurements were performed in the LHC tunnel and at different CERN sites on the surface. The devices to measure nanometre sized vibrations, the analysis techniques and the results are critically discussed and compared with former measurement campaigns. The implication of the measured integrated R.M.S. displacements and coherence length for the CLIC stabilization system are mentioned.

INTRODUCTION

CLIC is a high energy (0.5-3 TeV), high luminosity (2.3-5.9. 10^{34} $cm^{-2}s^{-1}$) Compact Linear Collider based on a two beam acceleration method currently under study. Strict alignment requirements exist for the different accelerator components to avoid emittance growth. Beam based, closed loop alignment mechanisms will be implemented for the girders with accelerating structures (ACS) and the Main Beam Quadrupoles (MBQ). Furthermore, micrometre and nanometre stability should be obtained for respectively the ACS and MBQ. The latter require active vibration stabilization to 1 nm vertical and 5 nm lateral integrated Root Mean Squared (R.M.S.) displacement at 1 Hz [1] as defined below (integrated RMS displacement values without mentioned frequency in this report are values at 1 Hz).

One of the disturbances is the ground motion. For more than 20 years, ground motion and vibration measurements were performed with several techniques to estimate its influence on emittance and beam orbit distortion in particle accelerators. A list of references can be found in [2]. Such minute vibration measurements are continued for the CLIC project as they are a useful way to characterize the environment of a particle accelerator, the influence of the choice of the tunnel, the different noise sources and they give input for the design of the accelerator components. The experience obtained can also give an input to further improve the measurement devices and analysis techniques used.

MEASUREMENT TECHNIQUES

Ground motion studies for accelerators can be carried out with different techniques. Each technique being better adapted in a certain frequency range with a corresponding required resolution. Relative displacement measurements based on hydrostatic levelling systems, wire positioning systems or LASER based techniques will give information in the frequency range below 1 Hz with a resolution of about 1 µm. This frequency region is of interest for the alignment. Absolute measurements with respect to an inertia frame are made with broadband seismometers, seismic accelerometers and tilt meters in a frequency range between 0.01 Hz and about 100 Hz. Standard accelerometers can be used for higher frequencies.

The results given in this paper are obtained with Güralp™ 40T and 6T seismometers, Endevco™ 86 and PCB™ 393B31 seismic accelerometers. The Güralp seismometers (1.6-2 kVs/m, 30 s to 50-80 Hz, values for 40T-6T) are used for frequencies between 0.1 and 40 Hz, the Endevco 86 (1 Vs^2/m, 0.01 to 200 Hz) seismic accelerometers between 40 and 100 Hz.

Ample time is allowed for the seismometers and accelerometers to reach a thermal equilibrium after installation and connection to the power supply. During the measurements the sensors were put under boxes to screen from wind and temperature variations.

The signal acquisition and analysis were made with a Muller BBM™ MKII analyzer. The resolution of the analyzer was 24 bit on ± 100 mV. The results from the analyzer were verified in Matlab™.

Coherence measurements were made with two Guralp 40T and Endevco 86 placed up to 1 km apart. Two analyzers were connected through 1 km long optical fibers for synchronization and data transfer. This synchronization method was developed and tested by Muller BBM. The phase error obtained this way was smaller than 0.01 deg at 256 Hz.

ANALYSIS TECHNIQUES

The ground motion is a combination of random and deterministic components. The Power Spectral Density (P.S.D.) for the signals down-sampled at 256 Hz is calculated for blocks of 64 s. Linear averaging was performed with 67 % overlap for 50 blocks, applying a Hanning window. Displacements are obtained by integrating velocity (seismometers) and acceleration (accelerometers) in each frequency bin. The duration of about 18 minutes for one measurement was chosen to have a sufficient statistical averaging [3]. In a frequency range between f_1 and f_2, the integrated R.M.S. is given by:

$$Integrated\ R.M.S.(f1\_f2) = \sqrt{\sum_{f1}^{f2} PSD(f)\Delta f}$$

The estimation of the error margin for such measurements is not straightforward. First of all, the calibration factor that is given for a nominal signal in a certain bandwidth is used for signals close to the resolution of the devices, assuming a linear behavior and unchanged bandwidth. Sub nanometre reference benches are currently being constructed to verify this [1].

Secondly, for low level signals the instrumental noise estimation is important. The measurement of the low instrumental noise of the sensors with the presence of a large background of ground vibration is done by placing two sensors side by side to measure the same background. The method mentioned in [4], based on coherence was used in this report to calculate the instrumental noise.

A signal to noise ratio between 5 and 13 was obtained for the integrated R.M.S. displacement between 0.1 and 3 Hz. The ratio is poor above 10 Hz and becomes 1 above 50 Hz. In some cases it was observed that with this method the calculated noise increases when the signal level increases, especially at peaks in the frequency domain.

MEASUREMENTS

P.S.D. and Integrated R.M.S.

Different sites were measured to examine the influence of tunnel depth and different noise sources. The curves of P.S.D. of vertical displacement show the increase of displacement with decreasing frequency (figure 1). Below 1 Hz the micro-seismic peak is the well known ground motion explained by movements of large masses of water in the oceans. The amplitude and frequency of the micro-seismic ground motion can change in time as seen on figure 1 for measurements carried out on different dates.

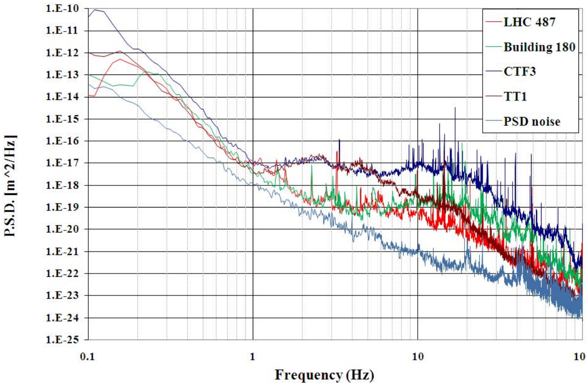

Figure 1: Power Spectral Density of the vertical displacement of the measured sites.

Above 1 Hz, the ground motion is governed by the so called cultural noise. Several peaks can be observed, related to machinery and structural resonances. Such peaks will appear as steps in the integrated R.M.S. curves (figure 2).

In the LHC tunnel, an integrated R.M.S. vertical displacement at 1 Hz between 2 and 3 nm was found at a depth of about 80 m and 487 m away from the ATLAS experiment and about 500 m away from a technical gallery.

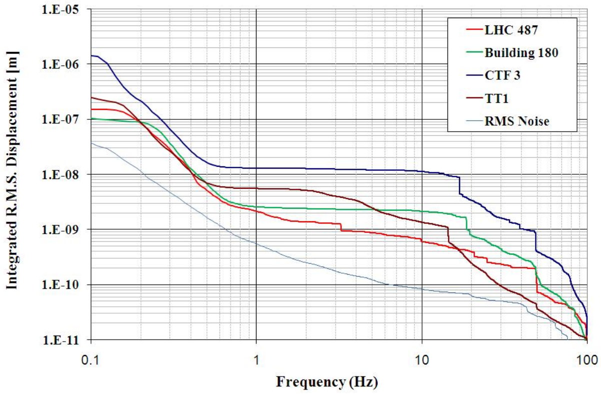

Figure 2: The integrated R.M.S. of the vertical displacement of the measured sites.

The proximity of the technical infrastructure of the ATLAS experiment or the technical gallery resulted in a vertical integrated R.M.S. that was 2 to 3 nm higher than at the position 487 m away from the ATLAS cavern. The measurements were made during the night with all the technical infrastructures (water cooling, ventilation, cryogenics) in operating conditions but without beam or magnetic field. Earlier tests in the LHC (or LEP) tunnel [5] [6] during a shut-down of most of the technical infrastructure showed an integrated R.M.S. value of about 1 nm.

An integrated R.M.S. displacement between 2 and 3 nm was also measured during the night on the large, thick concrete floor of surface building 180. There are very few noise sources on the floor of this building but it is near a road.

The TT1 site is a tunnel near the surface (estimated depth of about 10 m, under a small hill) on the CERN site. There are no technical installations running and the P.S.D. graph shows very few peaks above 10 Hz. An integrated R.M.S. of 6 nm at 1 Hz was measured during a week day; measurements during the night were not yet carried out. A detailed study about differences of cultural noise between day and night was published in [6]. The TT1 site was chosen as a location to build a low noise laboratory for characterization of CLIC stabilization components.

Finally, an integrated R.M.S. displacement of 13 nm at 1 Hz was obtained during the day in the CLIC Test Facility CTF3, a building on the surface, near several running technical installations but during a shutdown of CTF3 itself.

At 10 Hz, the smallest integrated R.M.S. vertical displacement of 0.6 nm was measured in the LHC tunnel. At other places it was above 1 nm. The P.S.D. and integrated R.M.S of horizontal displacements are similar to the vertical displacements, with the same order of magnitude.

As described above, an averaging is performed for 50 different blocks of 64 s. This averaging is needed to get a correct statistical value of the random signal but can give a wrong impression of how “quiet” a site is. In order to quantify the importance of intermittent excitations, the short-time Fourier transform is shown in figure 3. Peaks (deterministic perturbations) appear as vertical lines. Their size can vary some order of magnitudes when e.g. valves are opened, engines switched on. This variation disappears in the average. The arrows show an intermittent excitation at 3 Hz, at this frequency the corresponding displacements are significant.

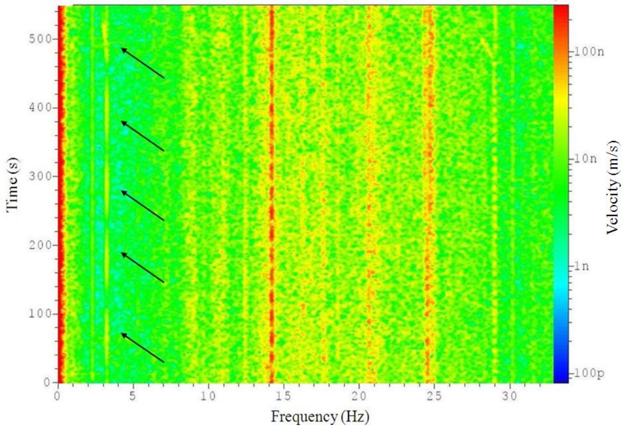

Figure 3: Color map of vertical vibrations in the LHC tunnel.

Coherence Length Measurements

Ground motion will create less emittance growth when the ground is moving in the same way over long distances. This can be expressed by the coherence of the ground motion measured by two seismometers put at a certain distance from each other. Tests were made for distances from 0 m up to 960 m in the LHC tunnel (Figure 4) and up to 157 m in building 180. A polynomial fit was made on the unruly vertical coherence curves for better reading. The coherence measured in the LHC tunnel dropped quickly after some metres for frequencies above 1 Hz. At 5 m distance e.g., the vertical coherence at 3 Hz was only 0.4. This fast decrease of coherence is explained by the presence of junctions between the concrete tunnel modules of about 10 m long.

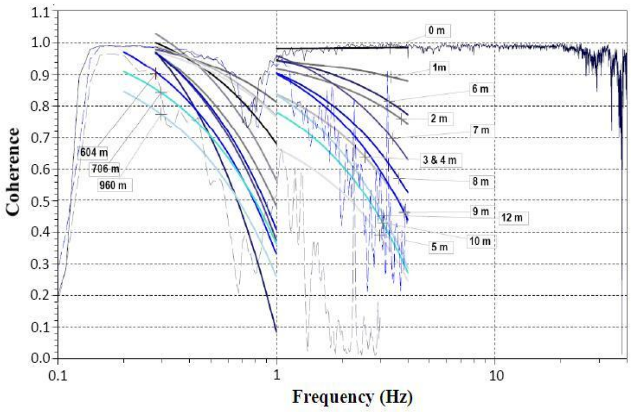

Figure 4: Vertical coherence measured over different distances in the LHC tunnel.

On the uniform concrete slab of building 180, the vertical coherence at 5 m distance for 3 Hz is still 1 and it takes more than 40 m for the coherence to drop to 0.4 at that frequency. For frequencies below 1 Hz the ground motion is coherent over several hundred metres. The micro seismic peak coherence is still almost 1 at 960 m distance and stays coherent up to 3 km [5]. Differences in amplitude of displacements of the accelerator components due to the thickness of the local geological layer or differences in support rigidity will not be revealed by coherence measurements.

CONCLUSIONS

The transducers, equipment and analysis techniques used for measuring ground vibrations with nanometre resolution for the CLIC stabilization are described in this paper. It is difficult to give an absolute measurement precision because of the instrument noise level, especially above 10 Hz. As there was however a sufficient signal to noise ratio in the frequency domain below 10 Hz, which contributes to most of the integrated R.M.S displacement at 1 Hz, the results are valid.

The integrated R.M.S. ground motion to be isolated by a stabilization system at CLIC can be expected to be several nm at 1 Hz. The depth of the tunnel will help to reduce cultural noise sources from the surface. Care should however be taken with noise coming from the important technical infrastructure for a large particle accelerator such as CLIC. Isolating the noise sources from the tunnel floor could be another option to reach the required stability as measurements on a surface building floor without noise sources showed a very low integrated R.M.S. at 1 Hz.

Finally, it was shown that accelerator components will move in a more coherent way over longer distances for frequencies above 1 Hz if the floor is built as a continuous, thick concrete slab.

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