STATUS OF THE CLIC STUDY ON MAGNET STABILIZATION AND TIME-DEPENDENT LUMINOSITY

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Abstract

The nanometer beam size at the CLIC interaction point imposes magnet vibration tolerances that range from 0.2 nm to a few nanometers. This is well below the floor vibration usually observed. A test stand for magnet stability was set-up at CERN in the immediate neighborhood of roads, operating accelerators, manual shops, and regular office space. It was equipped with modern stabilization technology. First results are presented, demonstrating significant damping of floor vibration. CLIC quadrupoles have been stabilized vertically to an rms motion of (0.9±0.1) nm above 4 Hz, or (1.3±0.2) nm with a nominal flow of cooling water. For the horizontal and longitudinal directions respectively, a CLIC quadrupole was stabilized to (0.4±0.1) nm and (3.2±0.4) nm.

1 INTRODUCTION

The CLIC study [1] aims at a 3 TeV collision energy with a transverse spot size of 43 nm (horizontal) times 1 nm (vertical). The associated magnet vibration tolerances are severe [2] (see Table 1). It must be determined early on whether they are feasible. Vibration data is analyzed via a power spectral density $P_d(f_k)$ of displacement with f_k as the discrete vibration frequency [3]. The integrated rms vibration I above a minimal frequency $f_{k_0} = f_{min}$ is:

$$I(f_{min}) = I(f_{k_0}) = \sqrt{\frac{1}{N\Delta T}\sum_{k=k_0}^{N/2} P_d(f_k)} \qquad (1)$$

Here, N is the number of samples, ΔT the sampling time, and k, k_0 are integers. The vertical direction is denoted by y, the horizontal by x and the longitudinal by z. The longitudinal direction is collinear with the beam and for our set-up perpendicular to the wide side of the table. Table 1 summarizes the requirements for the CLIC linac and final doublet (FD) quadrupoles [3]. The most challenging requirements are in the vertical plane with tolerances of 1.3 nm (linac) and 0.2 nm (FD) uncorrelated rms vibration above a minimal frequency of 4 Hz. Below f_{min} effects of magnet vibrations are cured by beam-based feedbacks. The value of f_{min} depends on the repetition frequency, the layout, and the gain of the feedback. About 25 pulses are needed for correction [2] so that for CLIC f_{min} is about 100 Hz/25.

A CLIC study on magnet stability was proposed [5] to address this critical issue. The study aims in particular at bringing existing stabilization technology to the accelerator field. In view of the available resources it was decided to buy existing industrial solutions instead of developing equipment directly adapted to the CLIC requirements.

Table 1: Summary of magnet stability requirements for a 2% loss in luminosity [3, 4].

Magnet	N_{magnet}	f_{min}	I_x	I_y
Linac	2600	4 Hz	14 nm	1.3 nm
Final Focus	2	4 Hz	4 nm	0.2 nm

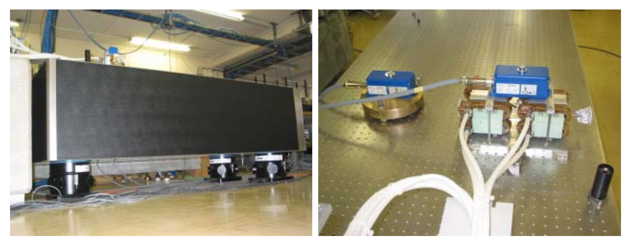

Figure 1: The CLIC vibration test stand. A honeycomb table with minimized structural resonances is supported by actively stabilized feet. A quadrupole doublet from the CLIC test facility is put onto the table and connected to cooling water. Geophones (blue) measure the vibrations on the floor, the table, and on top of the magnets.

2 EXPERIMENTAL SET-UP

A test stand for magnet vibration (see Fig. 1) was set up on the CERN site in Meyrin, in the immediate neighborhood of roads, operating accelerators, manual shops, and regular office space. Vibration properties were surveyed and found of appropriate level (not too low and not too high) [3]. The rms floor vibration above 4 Hz is about 6 nm and reflects the good geological conditions in the Geneva region. Though sub-nm stability is routinely observed in deep CERN accelerator tunnels [6], one cannot rely on this. Technical noise can easily enhance the vibration levels to the 5 nm level. The level of ground motion and technical noise at the CERN test stand is ideally suited to demonstrate that the critical CLIC vibration tolerances can be achieved in a realistic accelerator environment.

Advanced measurement and stabilization equipment was acquired or used from the CLIC alignment study [7]. The experimental set-up was completed in March 2002. The main components are described:

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1) Four geophones from GeoSig for monitoring vibration amplitudes with sub-nm accuracy in the frequency range of 1 Hz to 315 Hz. This includes options for analog and digitized data acquisition.

2) Four actively stabilized feet (STACIS2000 system from TMC), which rely on integrated geophones to measure ground vibration, rubber pads for passive damping, and piezo-electric movers for active damping of load vibrations induced from the ground.

3) A honeycomb support structure (table) with length 2.4 m, width 0.9 m, and height 0.6 m with a lowest structural resonance at 230 Hz.

4) A pneumatic system (PEPS system from TMC) consisting of four air piston supports for passive damping, distance sensors for micrometer alignment, and table top geophones for feedback on the air pressure (active damping).

Results achieved with items 1)-3) are reported, however, only using three STACIS feet (the fourth was broken). The pneumatic system was temporarily installed but detailed studies could not yet be performed. The present experimental set-up is illustrated in Fig. 1.

The sensors were carefully studied to establish the resolution and accuracy. In terms of rms vibration above a minimal frequency a resolution of better than 0.2 nm is obtained at 4 Hz and better than 0.1 nm at 10 Hz. The resolution improves for higher frequencies because velocity is measured. The absolute scale of the GeoSig sensors has recently been calibrated by the manufacturer. In order to assign an error to the absolute scale, the rms motion for frequencies between 2 Hz and 60 Hz is compared to the result from an older Mark Product sensor that was used for 1995 ground motion measurements [6]. In the range of valid measurements the Mark Product sensor systematically gives a 14% higher rms vibration, as shown in Fig. 2. A 14% error is assigned to the absolute scale. In the following all measurements refer to the GeoSig sensors.

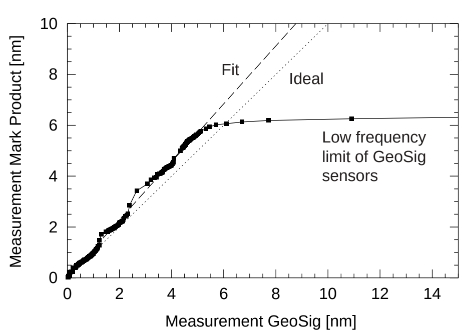

Figure 2: Rms vertical vibration measured for frequencies below 60 Hz with two different geophones.

3 CLIC QUADRUPOLE STABILIZATION

The vibration of the considered quadrupole doublet depends on the floor vibration, the damping from the active feet, sources of technical noise like cooling water, and structural resonances in table, quadrupole, and support.

The transfer function of vibration from the floor to the table top was studied. It is shown in Fig. 3. A vibration damping of up to a factor of 20 is achieved. With this damping the table top is stabilized in noisy conditions to (0.3±0.1) nm vertically (see Fig. 4), sufficient for the linac requirement and close to the requirement for the Final Focus magnet. The amplification above 200 Hz is a known problem [8] and is suspected to be due to electronic noise in the feedback circuit. It is not relevant for our application.

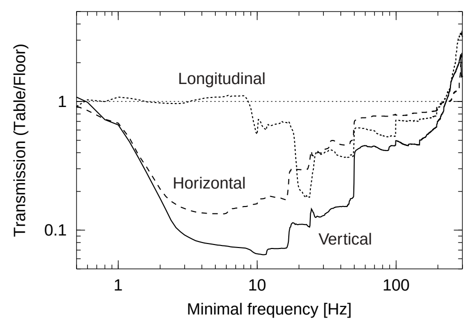

Figure 3: Transmission of horizontal, vertical, and longitudinal vibration amplitude from floor to table top.

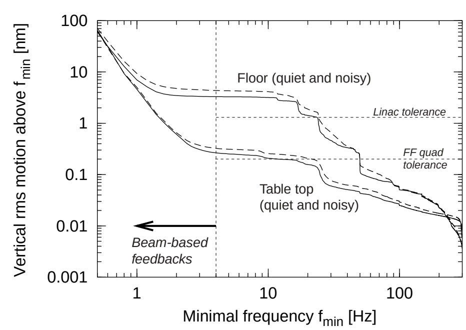

Figure 4: Vertical rms vibration versus frequency for quiet and noisy conditions at the floor and on the table top.

The quadrupole doublet was either directly screwed onto the table top or placed on its alignment support (micrometer alignment movers) that then was screwed onto the table. The measured vertical and horizontal vibration on floor, table, and quadrupole is shown in Fig. 5 for the direct connection to the table. At 4 Hz a vertical vibration amplitude of (0.9±0.1) nm is obtained on top of the quadrupole doublet. Vibration was reduced for all directions, with values of (0.4±0.1) nm and (3.2±0.4) nm for residual horizontal and longitudinal quadrupole vibrations above 4 Hz. The influence of cooling water on the vertical vibration level on top of the quadrupole is shown in Fig. 6. At 4 Hz and the nominal flow of cooling water the vertical vibration is increased to (1.3±0.2) nm which meets the tolerance for the CLIC linac quadrupoles. The studies on water induced vibrations are described in detail in [9]. Note that tap water was used for these studies, so that the effect of water pumps is not included (vibrations are generated from turbulent water flow).

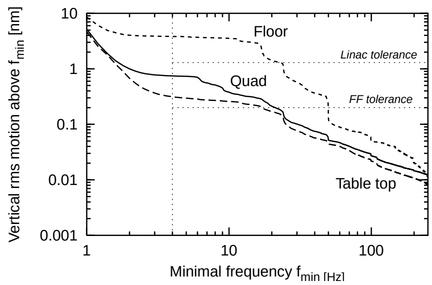

Figure 5: Vertical rms vibration versus frequency on floor, table, and quadrupole.

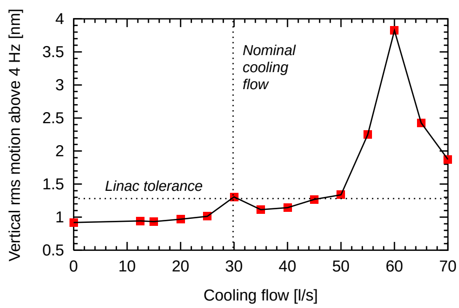

Figure 6: Vertical rms quadrupole vibration above 4 Hz versus flow of cooling water.

The transfer function of the CLIC quadrupole alignment support was studied with a speaker mounted onto the table. Acoustic waves were directed to the table to induce vibrations with a controllable frequency and amplitude. If the generated vibrations coincide with a structural resonance of the quadrupole support, a strong amplification in vibration amplitude from table to quadrupole is expected. Structural resonances were identified indeed. Inducing vibrations at 37 Hz an amplification of a factor of 10 in amplitude or 100 in power was measured between the quadrupole and table. The data is shown in Fig. 7 in the form of the power spectral densities with and without induced vibrations.

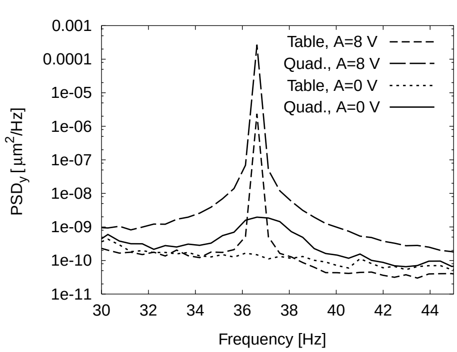

Figure 7: Power spectra for top of quadrupole and table around 37 Hz with and without acoustical noise at 37 Hz.

4 CONCLUSION AND OUTLOOK

A test stand for magnet vibration has been set up on the CERN main site and was equipped with advanced stabilization equipment. First measurements with active vibration damping showed suppression of floor vibration by up to a factor of 20. CLIC prototype quadrupoles have been stabilized vertically to an rms motion of (0.9±0.1) nm above 4 Hz, or (1.3±0.2) nm with a nominal flow of cooling water. For the horizontal and longitudinal directions a CLIC quadrupole was stabilized to (0.4±0.1) nm and (3.2±0.4) nm without cooling water. The measured vibration levels meet the requirements for the 2600 CLIC linac quadrupoles. A CLIC specific engineering solution could be based on or include the tested technology. Structural resonances were identified and can be minimized in future magnet designs. Further studies will aim at studying alignment stability and environmental effects (e.g. magnetic fields), employing an alternative pneumatic system, and using the measurements for predictions of the CLIC luminosity stability. Vibration must be suppressed by a further factor of 2-5 to meet the tolerance for the Final Focus quadrupole.

We thank F. Ruggiero for his encouragement and support. The colleagues at SLAC and DESY helped with many discussions and ideas.

5 REFERENCES

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