IN-SITU VIBRATION MEASUREMENTS OF THE CTF2 QUADRUPOLES

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Abstract

The Compact LInear Collider (CLIC), presently under study at the European Organization for Nuclear Research (CERN), aims at colliding high-energy "nanobeams" at a luminosity of $10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Vibrations of the lattice elements, if not properly corrected, can result in a loss in performance by creating both unacceptable emittance growth in the linear accelerator and relative beam-beam offsets at the interaction point. Of particular concern are the vibrations induced by the accelerator environment. For example, the circulating water used to cool the lattice quadrupoles will increase magnet vibration levels. In the framework of the CLIC stability study, in-situ measurements of quadrupole vibrations have been performed at the CLIC Test Facility 2 (CTF2) with all accelerator equipment switched on. Since the CTF2 quadrupoles and their alignment support structures are realistic prototypes of those to be used in the CLIC linac, the measurements provide a realistic estimate of the CLIC magnet vibrations in a realistic accelerator working environment.

INTRODUCTION

The second CLIC Test Facility (CFT2) was built to demonstrate the feasibility of the two-beam acceleration scheme at 30 GHz with high current drive beams [1], which the Compact LInear Collider [2] relies on. The CTF2 accelerator was operational until December 16^{th} 2002 and was located on the CERN Meyrin site, in a building at the ground level close to streets, parking lots, offices and normal working areas. In-situ vibration measurements of CTF2 girders and lattice quadrupoles were performed during the accelerator operation and shortly after the final CTF2 shutdown.

The CTF2 lattice quadrupoles are resistive magnets cooled with circulating water and have the same cross-section as the ones foreseen for the CLIC linac [3] but are 6 to 25 times shorter ($8\,$cm instead of $46\,$cm to $208\,$cm). Therefore, in-situ measurements of the CTF2 magnets provide a measure of the quadrupole vibrations in a realistic accelerator environment. Nevertheless, it must be noted that the designs of the CTF2 quadrupole and of its alignment support were not optimized against structural resonances nor were particular precautions taken to isolate/reduce sources of motion such as vibrating water pumps, powering systems and installations for the drive-beam line. The underground environment of CLIC must and will be designed to optimize all these potential sources of vibrations.

*Work done in the framework of a PhD program at the University of Lausanne, CH, High Energy Physics Institute (UNIL-IPHE).

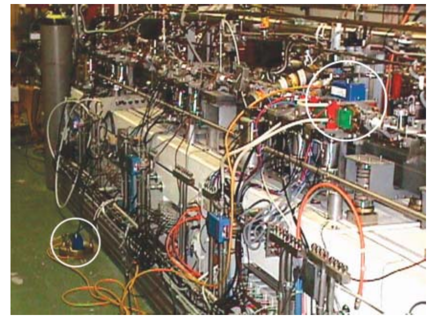

Figure 1: CTF2 accelerator where measurements are performed. White circles show the geophone installation.

In this paper, the results of the CTF2 measurements are presented. In Section , the experimental set-up is described and the basic notation for data analysis is given. In Section , the measurement results performed in various conditions are discussed. In particular, the effect of cooling water and electronic equipment are quantified by comparing measurements performed before and after the CTF2 shutdown. Some conclusions are drawn in Section .

EXPERIMENTAL SET-UP

A sector of the CTF2 accelerator is shown in Fig. 1. Vibration measurements were performed without beam but with all the machine equipments powered. The quadrupoles, together with the transfer line of the drive beam linac and several other equipments, are located on top of a concrete support (girder), which is glued on the concrete floor of the CTF2 building. Two or three quadrupoles are fixed on a common steel plate which sit on the alignment support. This is a complex structure, not optimized against structural vibrations, with 5 stepping motors that align the position of the magnets with respect to a reference stretched-wire system [4]. Only the longitudinal direction is left uncorrected since it does not require on-line alignment during operation. A similar system is envisaged for the CLIC linac quadrupoles.

Vibration measurements were taken simultaneously on the floor, on the concrete girder and on top of two quadrupole doublets by means of high-resolution seismometric *geophones*. The equipment for vibration measurements was setup in the framework of the CLIC Stability Study, as reported in detail in [5, 6]. Here, the basic notation for data analysis is briefly reviewed. The geophones measure the vibration velocity, $v(t_n)$, at the discrete times $t_n = n\Delta t$, with $n = 1, 2, ...N$. The sampling time Δt is typically set to $0.001\,$s. The geophones have a sub-nanometre resolution in the $4\,$Hz to $315\,$Hz frequency range. The error on the sensor calibration has been esti-

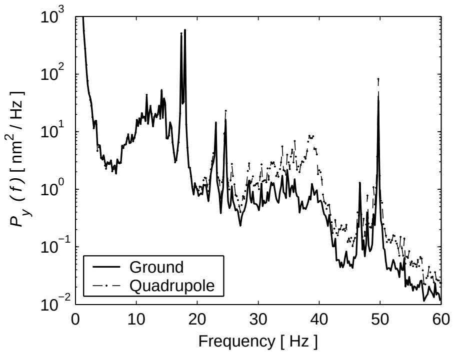

Figure 2: Vertical power spectral density, $P_y(f)$, versus frequency, f, as measured on the ground and on a CTF2 quadrupole with accelerator equipment switched on.

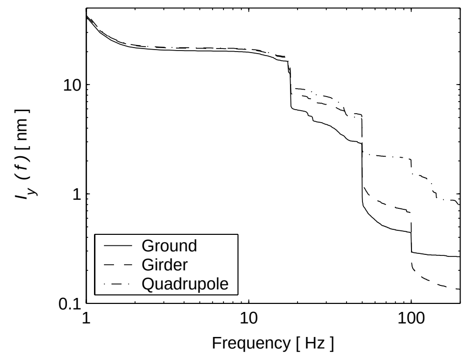

Figure 3: Vertical RMS motion, $I(f)$, versus frequency, f, as measured on ground, girder and quadrupole doublet.

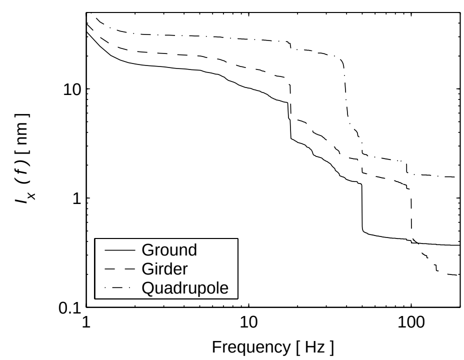

Figure 4: Transverse RMS motion as measured on the CTF2 ground, girder and quadrupole doublet when all the accelerator equipments are switched on.

mated independently of the manufacturer's calibration to be below the 10 % level [6]. The power spectral density of the displacement, $P(f_k)$ is defined for the discrete frequencies $f_k = \frac{k}{N\Delta t}$ as:

$$P(f_k) = \frac{N\Delta t^3}{2\pi^2 k^2} \left| \sum_{n=1}^{N} v(n) e^{-2\pi i \frac{kn}{N}} \right|^2 . \qquad (1)$$

The integrated RMS displacement induced by vibrations above $f_{min} = \frac{k_{min}}{N\Delta t}$ is then given by:

$$I(f_{min}) = \sqrt{\frac{1}{N\Delta t} \sum_{k'=k_{min}}^{k_{max}} P(f_{k'})}, \qquad (2)$$

where k_{max} corresponds to the largest measurable frequency. In order to reduce the statistical uncertainty on the measurement results, $P(f_k)$ is calculated as the average of several consecutive data sets before integration. According to the standard notation, y and x denote the vertical and horizontal direction with respect to the beam path.

MEASUREMENT RESULTS

Vibrations of floor, girder and quadrupoles

The vertical power spectral density as measured on the floor and on a quadrupole doublet is given in Fig. 2. All accelerator equipment is switched on (included the magnet cooling water system). The quadrupole features some resonances in the ≈ 30 Hz to ≈ 50 Hz range, which are induced by the alignment support structure. The vertical and horizontal RMS motions as measured on the floor, the girder and the magnet are given in Figs. 3 and 4. The RMS ground motion above 4 Hz is of the order of 20 nm. At this frequency, there is no significant amplification of vertical motion from the girder nor from the quadrupole support. Some amplification arises above approximately 20 Hz, where the aforementioned structure resonances become relevant. On the other hand, the horizontal motion above 4 Hz as measured on the magnet and the girder are 2 and 1.3 times larger than on the floor, respectively (see Fig. 4). Outside working hours, the RMS motion of the floor and quadrupoles is 1-2 nm smaller than in Figs. 3 and 4.

The vertical ground-to-girder transfer function is given in Fig. 5. This is calculated as the squared ratio of the power spectral densities simultaneously measured on the ground and the quadrupole. The resonance at the lowest frequency is found at approximately 40 Hz and increases the motion by 4 times with respect to the supporting ground. At larger frequencies, a number of other resonances arise, which amplify the motion up to a factor 100. It is noted that the latter resonances are of less con-

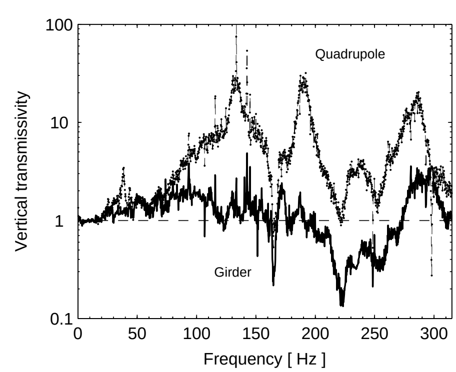

Figure 5: Vertical transmission from ground to girder (solid line) and to quadrupole (dotted).

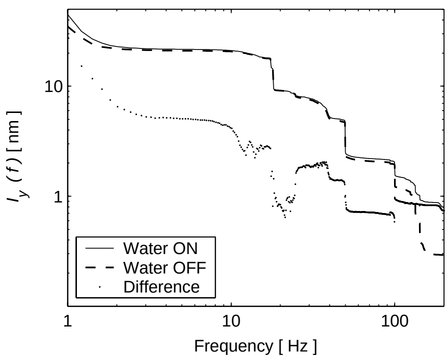

Figure 6: Vertical RMS motion of a CTF2 quadrupole as measured with (solid line) and without (dashed) cooling water. The RMS difference is also given (dotted line).

cern because at larger frequencies the vibration amplitudes are smaller and the overall induced RMS motion above ≈ 100 Hz is in the nm range (see Fig. 3). Horizontally the magnet support resonance at ≈ 40 Hz amplifies the motion by approximately 50 times. This explains the larger amplification of the total RMS motion above a few Hertz with respect to the vertical direction (see Fig. 4). Nevertheless, this should not be a serious issue for CLIC since the beam is ≈ 100 times wider than high and horizontal tolerances are less stringent.

Effect of cooling water

Measurements of quadrupole vibrations were performed with and without the cooling water. The results are summarized in Fig. 6, where the vertical RMS motion is plotted against frequency. The contribution of the turbulent water to the magnet vibrations is an uncorrelated contribution that adds in quadrature to the zero-flow vibrations [7]. The dotted line of Fig. 6 gives the squared difference of the of the lines with water on (solid line) and off (dashed line). With the nominal water flow (pressure of about 3.2 bar), the quadrupole vibration level is increased by between 4 nm to 6 nm depending on the measurement conditions and on the quadrupole under investigation. There are indications that the quadrupole motion is affected by vibrations generated upstream of the magnet cooling circuit, transmitted to the magnet via the water.

Effect of accelerator environment

Vibration measurements in the CTF2 building were repeated shortly after the CTF2 shut down (all equipment switched off) and compared with the measurements before shut down. This is shown in Fig. 7. The effect of the noise from the accelerator equipment is summarized in Table 1. The overall reduction of the vertical RMS motion above 4 Hz after the shut down is about 5 nm.

CONCLUSIONS

In-situ vibration measurements of CTF2 quadrupoles have provided useful information on the motion of CLIC

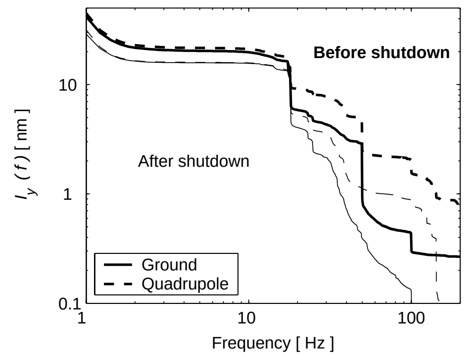

Figure 7: Vertical RMS motion as measured on the ground (solid line) and on a CTF2 quadrupole (dashed) before (bold lines) and after (thin lines) the machine shutdown.

Table 1: Vertical RMS motion above 4 Hz, 20 Hz and 60 Hz before and after the CTF2 shutdown.

	$I_y(4\,\mathrm{Hz})$	$I_y(20\,\mathrm{Hz})$	$I_y(60\,\mathrm{Hz})$
Ground - on	20.44 ± 2.04	5.84 ± 0.58	0.57 ± 0.06
Quadr. - on	21.75 ± 2.18	9.14 ± 0.91	2.25 ± 0.23
Ground - off	15.86 ± 1.59	4.02 ± 0.40	0.25 ± 0.03
Quadr. - off	16.00 ± 1.60	5.22 ± 0.52	1.02 ± 0.10

prototype magnets in a realistic accelerator environment. It seems that with a careful design of the girder and the magnet support structures the amplification of ground motion above a few Hertz can be kept under control. However, the accelerator environment is found to increase the magnet vibrations by approximately 5 nm with respect to the unperturbed case with all equipment off. The largest contribution is induced by the magnet cooling water system. Vibrations induced in the accelarator environment are a serious concern for future linear colliders. The accelerator equipment must be optimized against vibrations or active stabilization devices have to be envisaged to reliably achieve the required sub-nanometre magnet stability even if a quiet geological environment is chosen.

The authors would like to sincerely acknowledge R. Aßmann and I. Wilson and also E. Bravin and T. Lefèvre, who shared with us the very last hours of CTF2 run.

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