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PROOF OF CONCEPT OF CLIC FINAL FOCUS QUADRUPOLES STABILIZATION

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Abstract

The Compact LInear Collider (CLIC) [1] luminosity requires extremely low beam emittances. Therefore, high beam position stability is needed to provide central collisions of the opposing bunches. Since ground motion (GM) amplitudes are likely to be larger than the required tolerances, an Active Vibration Control (AVC) system is required to damp quadrupole motion to the desired value of 0.2 nm RMS at 4 Hz. This paper focuses on the vertical final focus quadrupoles (QD0, QF1) stabilization and demonstrates its feasibility. An AVC system to be installed under QD0 and QF1 has been developed and successfully tested at LAPP. Based on a dedicated homemade sensor with an extremely low internal noise level of 0.05 nm at 4 Hz, it damps GM in the frequency range [3;70] Hz by up to 30 dB, leading to RMS values of approximately 0.25 nm at 4 Hz. Simulations based on GM measured in the Compact Muon Solenoid (CMS) experimental hall [2] show that with such a GM level, the specifications would only be achieved with a Passive Insulation (PI) system, which would filter ground motion starting at ~ 25 Hz.

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Abstract

The Compact LInear Collider (CLIC) [1] luminosity requires extremely low beam emittances. Therefore, high beam position stability is needed to provide central collisions of the opposing bunches. Since ground motion (GM) amplitudes are likely to be larger than the required tolerances, an Active Vibration Control (AVC) system is required to damp quadrupole motion to the desired value of 0.2 nm RMS at 4 Hz. This paper focuses on the vertical final focus quadrupoles (QD0, QF1) stabilization and demonstrates its feasibility. An AVC system to be installed under QD0 and QF1 has been developed and successfully tested at LAPP. Based on a dedicated homemade sensor with an extremely low internal noise level of 0.05 nm at 4 Hz, it damps GM in the frequency range [3;70] Hz by up to 30 dB, leading to RMS values of approximately 0.25 nm at 4 Hz. Simulations based on GM measured in the Compact Muon Solenoid (CMS) experimental hall [2] show that with such a GM level, the specifications would only be achieved with a Passive Insulation (PI) system, which would filter ground motion starting at ~ 25 Hz.

INTRODUCTION

CLIC will collide electron and positron beams in two linear accelerators over a length of about 48 km, colliding them at the Interaction Point (IP) at an energy of 3 TeV with a peak luminosity of ~ $2*10^{34}$ $cm^{-2}s^{-1}$. Worldwide scientists and engineers have to demonstrate the feasibility to solve all the technological barriers. The beam is accelerated and guided thanks to several thousands of accelerating structures (Fig.1) , which are dedicated to the particle acceleration at the required energy, and heavy quadrupoles along the Main Linac, which maintain the beam inside the vacuum chamber to reach the required luminosity at the IP. The luminosity and the rate of physics events are correlated to the beam emittances (linked to the beam size) and the relative beam-beam offset at the IP [3]. Given the size of the beam, requirements on the vertical position are tighter. The desired performances are expressed in terms of displacement Root Mean Square (RMS), which is the integral of the Power Spectral Density (PSD) of the signal x within a given frequency range *(f)*, as detailed in equation *(1)*:

$$RMS_x(f_{min}) = \sqrt{\int_{f_{min}}^{\infty} PSD_x(f)df} \qquad (1)$$

As the future CLIC location site is still unknown, the reference GM is the one measured at LAPP (Annecy - France). This is also the location where the experimental tests were successfully done, achieving 0.25 nm RMS (4Hz). This paper is based on a previous study described in [4] and constitutes a proof of concept of such a vertical vibration control for CLIC thanks to an AVC prototype and a dedicated homemade vibration sensor. However, the future accelerator will benefit from different conditions, like the Large Hadron Collider (LHC) [5] at CERN, safely shielded by 50 – 100 meters of rock below ground. Thus, simulations have been done using GM measured in the CMS experimental hall, one of the multi- purpose detectors on the LHC. Conclusions draw the attention to the need to damp vibration > 100 Hz to achieve the specification. This could be done by placing a PI under the quadrupoles such as vibration isolation rubber pads.

EXPERIMENTAL SETUP AND RESULTS

Sensors

It has been demonstrated in former studies that the limitation of such active control is the sensor [6]. Indeed, standard sensors like geophones and accelerometers are mainly developed for monitoring and not for active control and their bandwidth covers the ones of these two technologies. Thus, a homemade vibration sensor (patent n° FR 13 59336) has been designed(see Fig. 2). It is based on an internal mass-spring-damper system and a capacitive sensor, which gives the relative motion between the mass and the GM. The GM can be deduced by a precise knowledge of the sensor's dynamic $L(s)$, see equation Eq. 2.

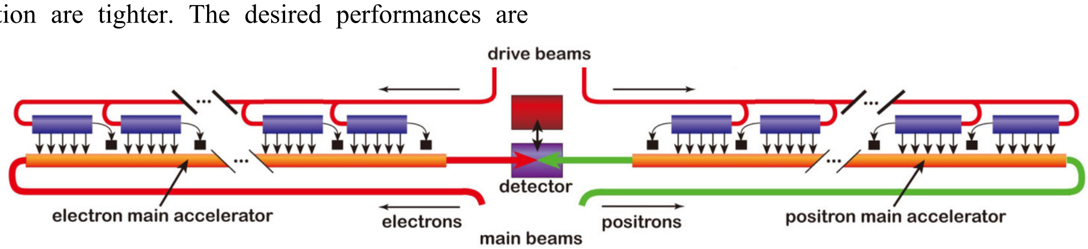

Figure 1: Layout of CLIC.

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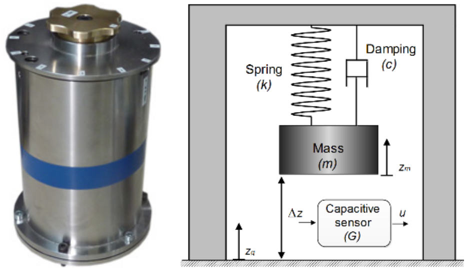

Figure 2: LAPP sensor image and layout.

$$L(s) = G\frac{\frac{1}{\omega_0^2}s^2}{1+\frac{2\xi}{\omega_0}s+\frac{1}{\omega_0^2}s^2}, \omega_0^2 = \frac{k}{m}, \xi = \frac{c}{2}\sqrt{\frac{1}{m.k}}, f_0 = \frac{\omega_0}{2\pi} \quad (2)$$

A comparative study has been realized simultaneously with two other technologies: geophone and accelerometer. Measurements have been performed in a very well adapted environment, which guarantees the quality of the GM coherence thanks to an optimized concrete. The setup of this measurement is described in [7]. The noise of each sensor has been characterized by measuring the seismic motion with two sensors of the same model placed side-by-side. The sensor noise is then calculated by using the corrected difference method [8]. The effective bandwidth of each sensor (i.e. the ability of the sensors to measure the seismic level in a specific environment) measured at LAPP is shown in Table 1.

Table 1: Usual Sensors Bandwidth and Noise Level

Sensor	Bandwidth [Hz] (constructor data)	Effective bandwidth [Hz] (measured)	Noise level RMS @ 4Hz [nm]
CMG-6T	[0.03 100]	[0.1 0.8]U[4 60]	0.1
731-A	[0.01 500]	[8 150]	0.5
LAPP	[0.1 3000]	[0.1 100]	0.04

Active Vibration Control System

The active vibration control system [9], Fig. 3, is designed in such a manner that it is rigid enough to avoid spurious frequencies in the interested bandwidth [1 – 300 Hz]. The control strategy is based on previous studies [4], [6], and similar research work [10] but instead of using up to 4 sensors for FeedBack (FB) and feedforward, it has been optimized by using only one LAPP sensor in a FB loop.

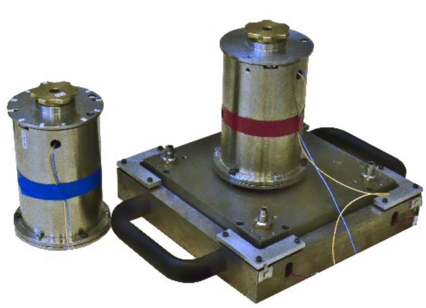

Figure 3: Active Vibration Control system, LAPP sensors for GM measurement (blue) and FB control (red).

A second LAPP sensor identical to the FB sensor is used to measure GM and to determine the achieved attenuation. The following block diagram (Fig. 4) is a simplified scheme of the whole process. In the experimental hall at LAPP, a damping ratio of 8.5 has been achieved at 4 Hz, leading to a RMS displacement of the support of 0.25 nm. Note that at LAPP, no PI was needed as the experimental hall benefits from a quiet environment (for f > 100 Hz).

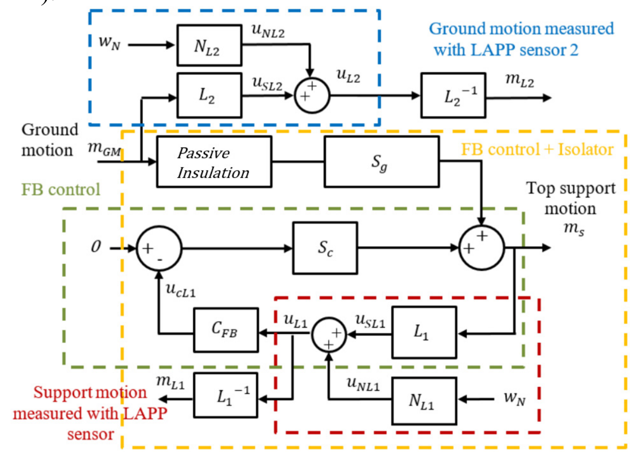

Figure 4: Block diagram of the FB control loop.

SIMULATION WITH LHC GM

As shown in Fig. 5 and Fig. 6, high frequency GM (f > 100 Hz) measured at LHC is unneglectable. AVC system is not able to attenuate GM in this range because of sensor limitation.

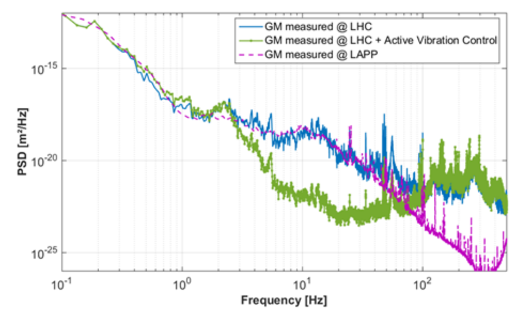

Figure 5: PSD of the - GM measured at LHC (solid line), GM at LHC + Active Vibration Control (spotted lined), and GM measured at LAPP (dotted line).

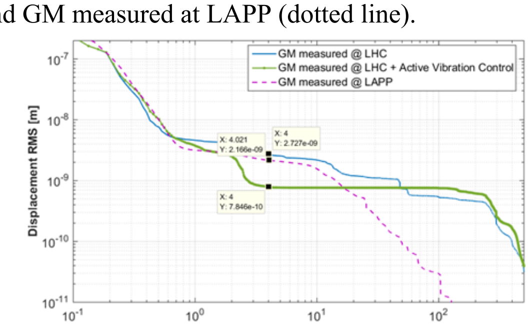

Figure 6: RMS of the - GM measured at LHC (solid line), GM at LHC + Active Vibration Control (spotted lined), and GM measured at LAPP (dotted line).

A PI is needed such as vibration isolation rubber pad (see Fig. 7) placed under the quadrupoles. The natural frequency is tunable, and depends on the surface of the pad versus weight of the quadrupole. A value of 25 Hz

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has been chosen, leading to a motion that fits the one measured at LAPP.

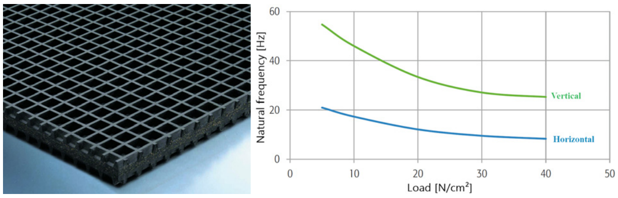

Figure 7: Example of usable PI (Biltz® B13W- vibration isolation rubber pad).

The simulation with GM at LHC and PI gives the following results (Fig. 8 & Fig. 9) :

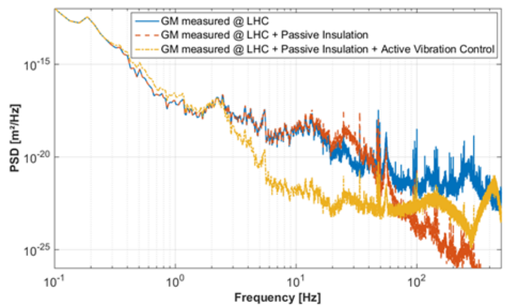

Figure 8: PSD of the - GM measured at LHC (solid line), GM at LHC + Active Vibration Control (dotted lined), and GM at LHC + AVC + PI (dash-dotted line).

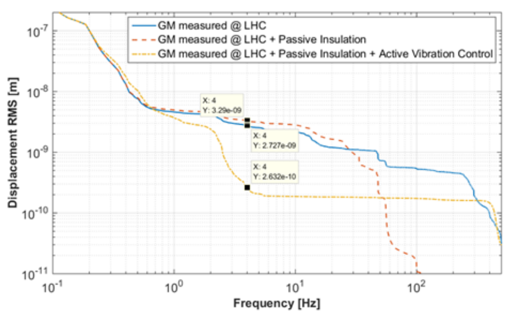

Figure 9: RMS of the - GM measured at LHC (solid line), GM at LHC + Active Vibration Control (dotted lined), and GM at LHC + AVC + PI (dash-dotted line).

In simulation, a damping ratio of 10 has been achieved at 4 Hz, leading to a RMS displacement of the support of 0.26 nm. The achieved attenuation is given in the Fig.10 .

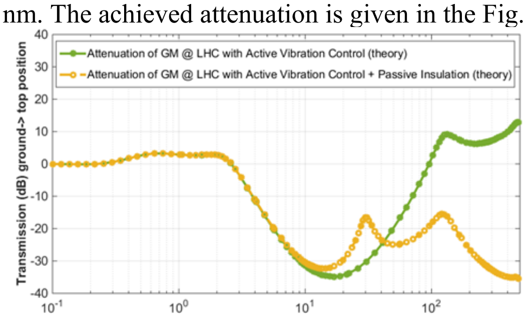

Figure 10: GM attenuation obtained with AVC and passive insulation.

CONCLUSION

This study attempts to solve one of the most critical technical aspects of the future CLIC particle collider. A dedicated control strategy for ground motion mitigation is detailed. Based on a AVC system and a new homemade sensor of vibrations, the designed control is validated experimentally at LAPP by implementing it on real time hardware using dSPACE work-station DS1006. It is demonstrated that this sensor is well adapted to real time FB control with the AVC system, a damping ratio of 8.5 has been achieved at 4 Hz, leading to a RMS displacement of the support of 0.25 nm. Simulations have been realised in a more realistic environment, where the GM is the one measured in the CMS experimental hall. Results have shown the necessity to damp GM with vibration isolation rubber pads. In such a configuration, it has been possible to reach the same performances as the one obtained experimentally at LAPP, with a RMS displacement of the support of 0.26 nm and a damping ratio of 10.

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