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ACTIVE VIBRATION ISOLATION SYSTEM FOR CLIC FINAL FOCUS

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Abstract

With pinpoint accuracy, the next generation of Linear Collider such as CLIC will collide electron and positron beams at a centre of mass energy of 3 TeV with a desired peak luminosity of $2*10^{34}$ $\mathrm{cm}^{-2}\mathrm{s}^{-1}$. One of the many challenging features of CLIC is its ability to collide beams at the sub-nanometer scale at the Interaction Point (IP). Such a high level of accuracy could only be achieved by integrating Active Vibration Isolation systems (AVI) upstream of the collision to prevent the main source of vibration: Ground Motion (GM). Complementary control systems downstream of the collision (Interaction Point FeedBack (IPFB), Orbit FeedBack (OFB)) allow low frequency vibration rejection. This paper focuses on a dedicated AVI table designed for the last focusing quadrupole (QD0) where the specifications are the most stringent. Combining FeedForward (FF) and FeedBack (FB) techniques, the prototype is able to reduce GM down to 0.6 nm RMS(4Hz) experimentally without any load. These performances couldn't be achieved without cutting edge-technology such as sub-nanometer piezo actuators, ultra-low noise accelerometers and seismometers and an accurate guidance system. The whole AVI system is described in details. Further developments concern the integration of the final focusing magnet above the AVI table, first as part of the simulation with its dynamical model, and finally, as a realistic prototype.

INTRODUCTION

Two linear colliders are currently under study by international scientific collaborations to explore new energy region beyond the capabilities of the current particle accelerators: ILC (International Linear Collider) [1] and CLIC (Compact Linear Collider) [2]. This paper is dedicated to CLIC which will accelerate electrons and positrons in two linear accelerators over a total length of about 48 km. The beam is accelerated and guided thanks to several thousands of accelerating structures which are dedicated to the acceleration of the particles at the required energy and heavy quadrupoles along the Main Linac (ML) which maintain the beam inside the vacuum chamber to reach the required luminosity at the Interaction Point (IP) (see Figure 1). The objective is to collide the electron and positron beams at the IP with center of mass energy of 3 TeV with a nominal luminosity of 2×10^{34} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$. 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 Interaction Point (IP) [3]. As the shape of the beam is elliptic (whose size is σ_x = 0.7 nm and σ_y = 60 nm), requirements on the vertical position of the beam are tighter (see Table 1). 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)*:

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

Table 1: Specifications of CLIC Beam Stabilization

Location	Number of magnets	Vertical beam offset	Lateral beam offset
Linac [4]	4000	1,5 nm RMS @ 1 Hz	5 nm RMS @ 1 Hz
Interaction Point [3]	2	0,2 nm RMS @ 0,1 Hz*	5 nm RMS @ 1 Hz

* Note that the specification at the IP of the AVI system is 0.2 nm RMS(4) as the IPFB should take over below 4 Hz.

ACTIVE VIBRATION ISOLATION SYSTEM

The future CLIC tunnel is obviously not yet operational, so the reference Ground Motion (GM) is the one measured at LAPP. However, the future accelerator will probably benefit from better conditions, like the Large Hadron Collider (LHC) at CERN [5], safely shielded by 50 – 100 meters of rock below ground.

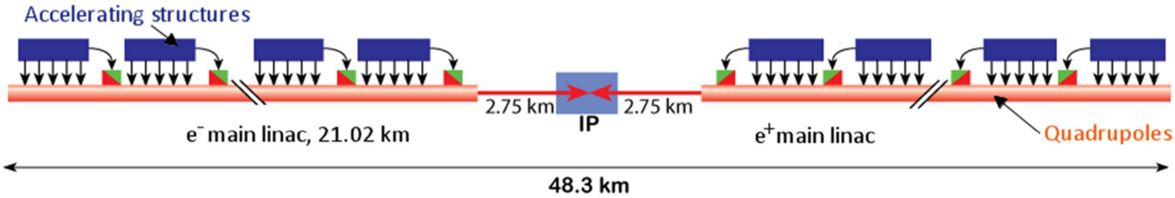

Figure 1: Simplified layout of CLIC.

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Figure 2 shows the PSD and the RMS of the GM displacement at LAPP and at the Compact Muon Solenoid (CMS) [6] experimental hall, one of the multi-purpose detectors on the LHC, representative of the detectors of the future CLIC. Note that the ground motion is the main disturbance of these focusing magnets. It is due to natural seismic motion (mainly observable at low frequencies) and disturbances due to human activities on a large bandwidth starting from one Hz to a few hundreds of Hz.

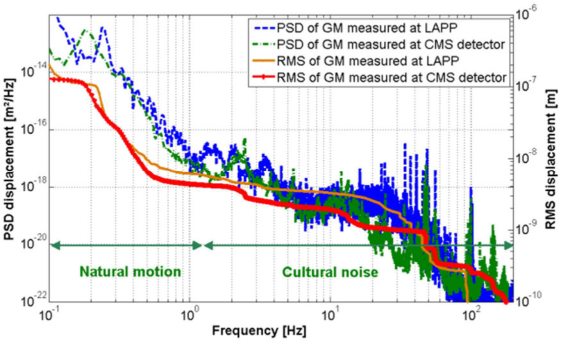

Figure 2: PSD and RMS of GM measured at LAPP and at CMS detector.

The active vibration isolation system [7] is equipped by commercial products (see Figure 3). It is composed of internal capacitive sensors for tuning, elastomeric strips for guidance and four coupled piezoelectric actuators for action. The latter are produced by CEDRAT Technologies (CTEC). This support is designed in such a manner that it is rigid to avoid spurious frequencies in the interested bandwidth [1 – 300 Hz].

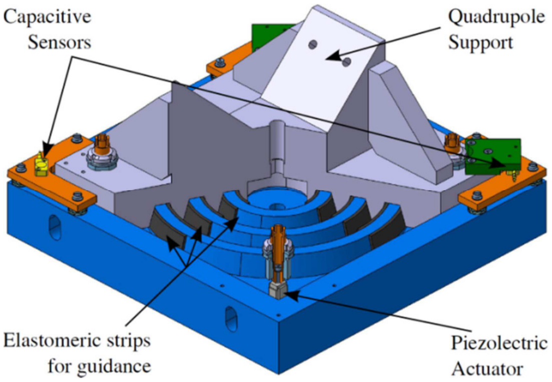

Figure 3: The developed active support.

A specific active control was developed to manage this active support, excited by seismic disturbances, at a sub nanometer scale. Such a system requires measuring very small displacements on a large bandwidth. A selection of the best commercial sensors has been performed [8] and two types of sensors are used: the Guralp 6T geophones and the Wilcoxon 731A accelerometers. The combination of both sensors allows accurate measuring on the desired large bandwidth [1 – 300 Hz].

A very accurate and efficient simulation tool has been designed to generate the control laws and can be used as a powerful predictive tool. It takes into account all the models of the different devices, the dynamic behavior of the structures, the seismic disturbances, all the electronic noises and the numerical constraints due to the data processing, the analog-digital converters and the real time processing. For the AVI system, four controls in real time are performed simultaneously, two FF using an accelerometer and a geophone on the ground and two FB using an accelerometer and a geophone on the active support (see Figure 4 and Figure 5).

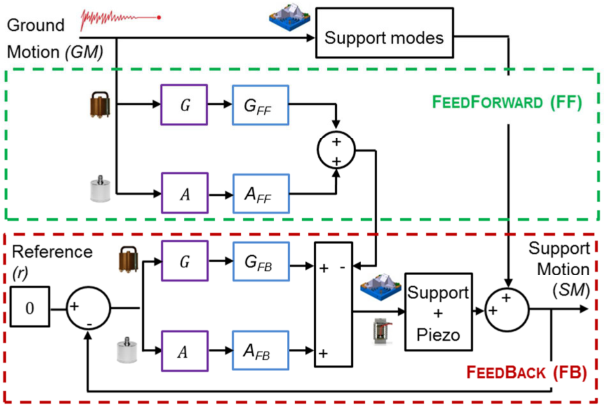

Figure 4: Simplified bloc scheme of the control.

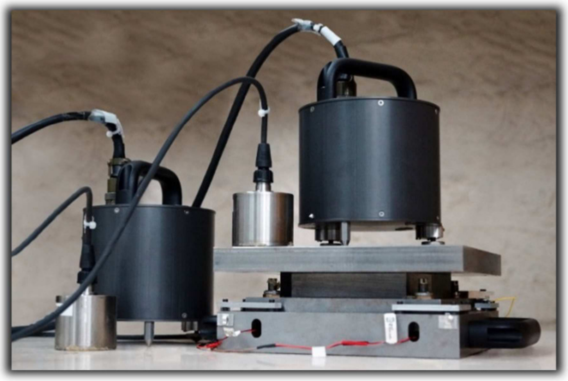

Figure 5: Prototype of the AVI system.

An absolute displacement of 0.6 nm integrated RMS at 4 Hz was obtained [9] (see Figure 6). This great result, even if it is not enough regarding the required CLIC specifications, is an important step for the collider research and development and more generally in vibration control field.

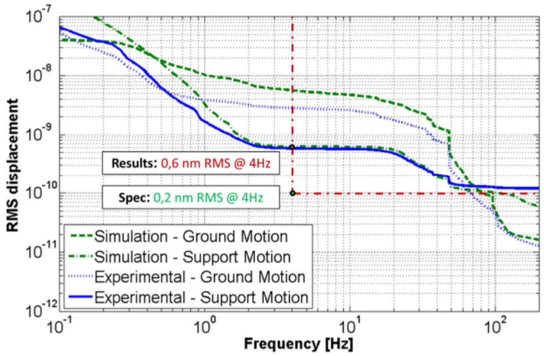

Figure 6: Obtained results at a sub-nanometer scale.

FURTHER DEVELOPMENTS

Seismic Sensors

All the developments have pointed out that the seismic sensors were the main limitation of the active support (See Figure 7a). This limitation is mainly due to the instrumental noise and to the model of the sensor which is generally not adapted for control. For these reasons, a seismic sensor is currently under development and a patent under review. Different prototypes were processed (See Figure 7b). The obtained performances are similar to the Guralp 6T at low frequencies while having a greater measurement bandwidth, a more adapted model for control and a more compact size. It presents a sensitivity of 0.66 V/µm and a noise of 0.5 nm integrated RMS at 4Hz. The sensor's development will be pursued during the next years.

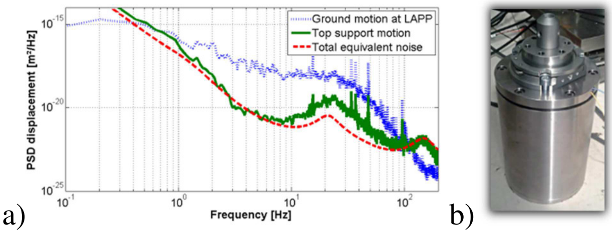

Figure 7: a) Performances limitation due to the sensors b) Picture of a homemade seismic sensor prototype.

QD0 Prototype

For budget reasons, the QD0 magnet will not yet be machined. Only a slice of it has already been produced by CERN for various tests such as magnetic fields or modal analysis. However, a real scale structure (a "dummy magnet") will be designed and machined. The goal is to reduce the cost while maintaining the same main characteristics (dynamic behavior, dimensions, load…). Thus, an accurate knowledge of the dynamic behavior of QD0 is required for machining and control purposes. These two actions are in progress and the finite element method (FEM) study of QD0 magnet is already achieved (see Figure 8). Furthermore, a state space representation of QD0 has been generated from FEM study and will be used for control system design.

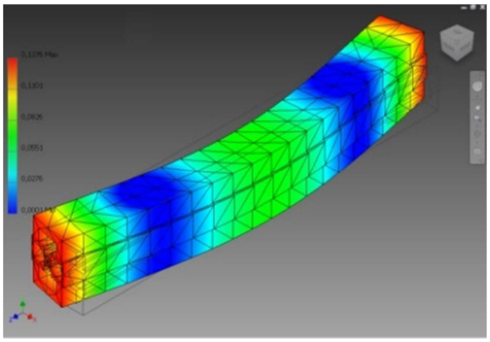

Figure 8: Finite element study of QD0.

The dummy QD0 magnet structure conception remains to be done as well as integrating it in a complete test bench with the dedicated instrumentation and interfaces.

CONCLUSION

This study attempts to solve one of the most critical technical aspects of the future CLIC particle collider. In this prospect, a dedicated control strategy for ground motion mitigation is detailed. The control strategy consists in the cumulative action of acceleration and velocity FF control combined with FB loops. The performance of the control, defined by the ratio RMS_{GM}/RMS_{SM} (SM being the top Support Motion) is about 5 at 4 Hz, leading to a $RMS_{SM}(4)$ of 0.6 nm, comparable to the best stabilization strategies. Possible ways for improving performance in GM concerns the sensors' limitations. Ongoing research efforts concentrate on sensors with better performances for this dedicated study with the help of the validated simulation program. The next step will be the conception and integration of the dummy QD0 on top of the support to address additional specifications.

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