Compatibility and Integration of a CLIC Quadrupole Nanometre-Stabilization and Positioning system in a Large Accelerator Environment

Artoos, K (CERN) *et al*

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COMPATIBILITY AND INTEGRATION OF A CLIC QUADRUPOLE NANOMETRE-STABILIZATION AND POSITIONING SYSTEM IN A LARGE ACCELERATOR ENVIRONMENT*

K. Artoos, C. Collette, P. Fernandez Carmona, M. Guinchard, C. Hauviller, S. Janssens, A. Kuzmin,
A. Slaathaug, M. Sylte CERN, Geneva, Switzerland

Abstract

A prerequisite for a successful nanometre level magnet stabilization and pointing system is a low background vibration level. This paper will summarize and compare the ground motion measurements made recently in different accelerator environments at e.g. CERN, CESRTA and PSI. Furthermore the paper will give the beginning of an inventory and characterization of some technical noise sources, and their propagation and influence in an accelerator environment. The importance of the magnet support is also mentioned. Finally, some advances in the characterization of the nanometre vibration measurement techniques will be given.

INTRODUCTION

CLIC is an electron-positron collider in the multi TeV range currently under study and in preparation of a conceptual design report [1]. The main beams are accelerated in structures ACS with RF power that is extracted via waveguides and Power Extraction and Transfer Structures (PETS) from a high intensity drive beam that runs parallel to the main beam. This extraction scheme is repeated in 2 m long "modules" over the total length of 42 km. The two main beams will collide at the interaction point I.P. with a design luminosity of $5.9x10^{34}$ cm^{-2}s^{-1}. To reach this luminosity, the transverse beam dimension at the I.P. should be 1 nm in vertical and 45 nm in the horizontal direction. For this purpose, about 4000 modules will contain Main Beam Quadrupoles (MBQ) with a length from 420 (type 1) to 1915 mm (type 4). To reach the design luminosity, a high mechanical stability of the magnetic axis of the MBQ and final focussing doublets at the I.P. is required. The vertical integrated R.M.S. displacement [2] should not be higher than 1 nm at 1 Hz for the MBQ [3] and 0.2 nm at 4 Hz for the Final Focus quadrupoles. The required horizontal stability is 5 nm at 1 Hz for the MBQ and at 4 Hz for the Final Focus. Although most information in this paper is of use for the Final Focus, it is mostly aimed at the MBQ stabilization. The frequencies of 1 Hz and 4 Hz are indicative frequencies below which jitter can be corrected with beam based feedback with corrector dipoles. One of the studies for the MBQ mechanical stabilization is based on a very stiff stabilization support in order to increase robustness against external forces [2].

This stiff support also introduces the possibility to use the actuators of the stabilisation system to reposition the MBQ in between beam pulses with nanometre precision and with micrometre range as an alternative for corrector dipoles.

STATE OF THE ART IN STABILIZATION

Mechanical stabilization to the nanometre scale is a concern in various fields of precision engineering such as semi conductor lithography, atomic force microscopy and nanotechnology. The specificity of the nano-stabilization of the CLIC MBQ compared to such fields is the frequency of 1 Hz, resulting into high sensor resolution requirements. The 4000 MBQ with masses between 100 and 400 kg constitute also a higher payload than what is most often found. Some comparisons may exist with large telescopes like ELT or gravitational wave detectors. A few former experiments of quadrupole stabilization for particle accelerators were compared in [4]. A general observation in those experiments is the sharp decrease at 1 Hz for the ratio of integrated RMS displacement with and without stabilization (fig. 1). Several commercial systems can indeed isolate by more than a factor 10 at several Hz, however this drops quickly to a factor 2 or 3 at 1 Hz. Without pretending a full analysis, the main reasons behind this are resolution limits of the used instrumentation and difficulties in the design of mechanical systems with low resonant frequencies.

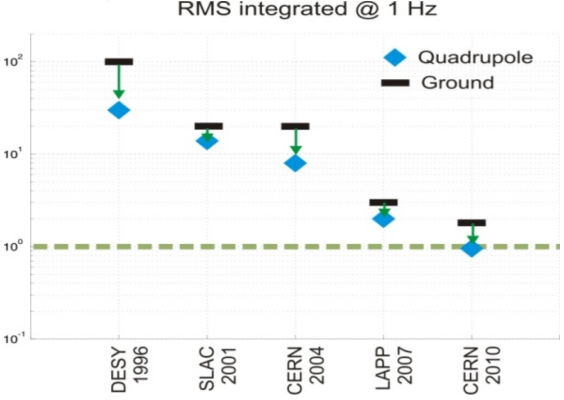

Figure 1: Decrease of integrated R.M.S. ratio at 1 Hz (nm) in stabilization experiments of quadrupoles

In the precision engineering applications mentioned above, all is done to remove possible vibration sources near the stabilized structure. The equipment is placed underground, in temperature controlled rooms with foundations separate from auxiliary technical infrastructure. For some applications like gravitational wave detectors the high vibration isolation is obtained by adding several passive isolation stages. In contrast to this, a stabilized particle accelerator component will be surrounded by and even connected to vibration sources.

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This is especially the case for CLIC where two high power particle accelerators are housed in the same tunnel.

INVENTORY FOR STABILITY

Measurement and Analysis Techniques

The instrumentation, acquisition, standardised measurement and analysis methods and instrumental noise estimation are described in detail in [5].

Ground Motion

In 2009, several ground motion measurements were made by CERN for the CLIC project in accelerator environments. On figure 2, the night time P.S.D. of three particle accelerators in operation (LHC (CERN), CesrTA (Cornell), SLS (PSI)) are compared. The amplitudes below 3 Hz are very similar, with some variation of the micro-seismic peak that depends on meteorological conditions above the near oceans. Above 3 Hz, the "cultural noise" of the surface is attenuated by the depth of the tunnel (LHC 80 m, CesrTA 15 m, SLS surface building). The resulting RMS integrated vertical displacements for several sites during the night (except CMS during the day) is shown on figure 3.

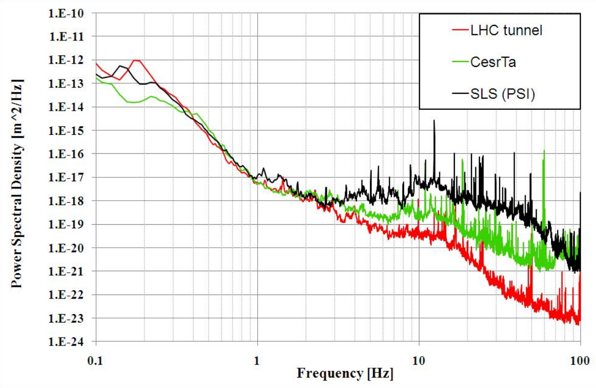

Figure 2: Vertical Power Spectral Density in three particle accelerators in operation

An important observation is the increase of instrument noise with higher ground motion (grey noise curves for high and low levels on figure 3).

Day and night time variation was studied in [6] and can vary up to a factor 5 for sites on the surface and a factor 2 for deep tunnels. Measurements in a shallow tunnel without technical infrastructure at CERN (TT1, about 10 m deep) showed an increase from 2 to about 5 nm between night and day.

The integrated RMS vertical displacement increases from 2 nm in the LHC tunnel up to about 10 nm near a technical cavern or an experimental cavern like CMS [7]. Distance attenuates such vibration sources quickly; the influence of a technical cavern in the LHC is greatly reduced at about 100 m. Adapted civil engineering of caverns and preventive measures such as e.g. vibration absorbers on pumps can further limit the impact on the main tunnel.

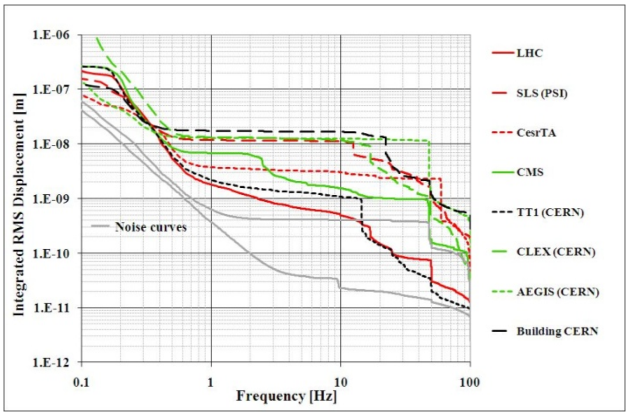

Figure 3: Vertical integrated RMS displacement at several sites

Coherence of the ground motion is often mentioned as a beneficial factor. For frequencies above 1 Hz however, vibrations are coherent to maximum 40 m on continuous concrete slabs and to only some metres in a tunnel structure with expansion joints.

Magnet Support

The ground motion is a broad band excitation with decreasing amplitude with increasing frequency. This excitation is amplified on the accelerator components at the support resonant frequencies. This is a constant worry in light sources and several lessons were learned from this for the CLIC MBQ support. In the first place, an eccentric cam alignment system based strategy was selected for the first type 4 MBQ alignment system for its expected rigidity. Secondly, an effort was made in the CLIC module design to lower the beam height to 620 mm [8]. A significant advantage is the relatively low mass of the MBQ. The mass of the stabilization system and intermediate parts should nevertheless be minimised. Even if the hertzian contact of an eccentric cam system can be designed theoretically extremely stiff, measurements in light sources have shown that the whole support can show resonances at rather low frequencies.

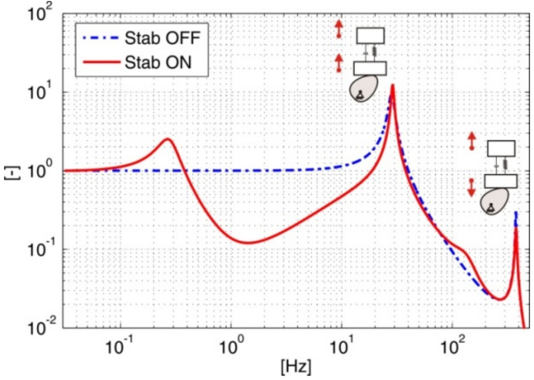

Figure 4 Transmissibility between the ground and the quadrupole for a two d.o.f. system with stabilization on/off

The eventual impact of a spurious mode of the alignment stage at e.g. 30 Hz in series with the studied stabilization system with the resonance at 350 Hz (rigid option) is considered (fig. 4). The performance of the stabilization is strongly affected at that frequency. However, with the input of a typical low level ground vibration spectrum, the spurious mode at 30 Hz does not make a significant contribution at 1 Hz (fig. 5).

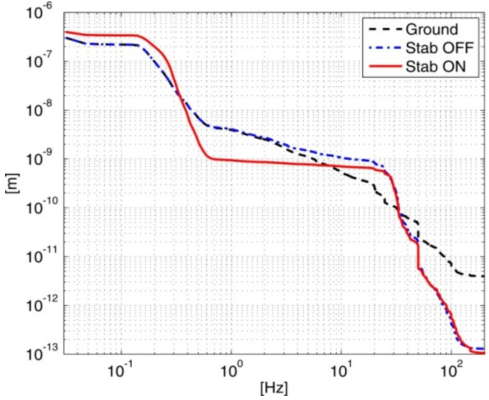

Figure 5: RMS integrated displacement with a spurious mode at 30 Hz of the alignment support

Water Cooling

After the ground motion, the vibrations induced by the water cooling can be expected as the most important vibration source. In CLIC, a large fraction of the power will be dissipated in the PETS, ACS, drive beam and main beam quadrupoles and this heat is evacuated by cooling water. Several vibration measurements were performed on water cooled components with very different results due to very different conditions. Turbulent water flow creates a broadband excitation and amplification at resonances of magnet supports or even of surrounding ACS [9] can increase the integrated RMS by more than 100 nm. Transmission of pump vibrations, pipe resonances and vibrations created by flow adjusting valves and gauges can also lead to a large RMS increase as measured in [10].

Forces acting directly on the quadrupole will create lower displacements with a stiffer magnet support as confirmed by measurements in [11] and specifically for soft versus rigid stabilization systems in [12]. The choice of a very rigid stabilization system [2] seems hence the right choice. A prototype CLIC MBQ with adjustable features will allow to test and reduce the influence of cooling water.

Vacuum and Vacuum Pipes

The vacuum in a central vacuum reservoir connected to both beams will be obtained with ion pumps and NEG during beam operation [8]. Although no vibrations can be expected from this vacuum system, the vacuum reservoir will easily transmit vibrations longitudinally and between drive and main beam and should hence be carefully designed.

Ventilation

A compartmented, transversal and hence smaller air flow rather than a longitudinal air flow is currently foreseen for the CLIC ventilation. This should be more compatible with the vibration stability.

Compatibility

The stabilization sensors, actuators and eventual elastomers for damping should be radiation hard and insensitive to stray magnetic fields. Furthermore, the required resolution demands short lead wires imposing local controller hardware screened from radiation.

CONCLUSION

The expected achievable performances above 1 Hz of state of the art stabilization systems imposes a back ground level that is for the moment at most a factor five higher than the required limit. Measurements have shown that this can be reached in deep tunnels if special care is taken for the design of the technical caverns and the presence of vibration sources in the tunnel. The alignment and stabilization system should be as rigid as possible in order to avoid amplification at low frequency modes. This rigidity is also required in order to be robust against the forces acting directly to the quadrupoles due to water cooling.

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