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STATUS OF GROUND MOTION MITIGATION TECHNIQUES FOR CLIC

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Abstract

The Compact Linear Collider (CLIC) accelerator has strong stability requirements on the position of the beam. In particular, the beam position will be sensitive to ground motion. A number of mitigation techniques are proposed - quadrupole stabilisation and positioning, final doublet stabilisation as well as beam based orbit and interaction point (IP) feedback. Integrated studies of the impact of the ground motion on the CLIC Main Linac (ML) and Beam Delivery System (BDS) have been performed, which model the hardware and beam performance in detail. Based on the results future improvements of the mitigation techniques are suggested and simulated. It is shown that with the current design the tight luminosity budget for ground motion effects is fulfilled and accordingly, an essential feasibility issue of CLIC has been addressed.

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Abstract

The Compact Linear Collider (CLIC) accelerator has strong stability requirements on the position of the beam. In particular, the beam position will be sensitive to ground motion (GM). A number of mitigation techniques are proposed — quadrupole stabilisation and positioning, final doublet stabilisation as well as beam-based orbit and interaction point (IP) feedback. Integrated studies of the impact of the GM on the CLIC Main Linac (ML) and Beam Delivery System (BDS) have been performed, which model the hardware and beam performance in detail. Based on the results, future improvements of the mitigation techniques are suggested and simulated. It is shown that with the current design the tight luminosity budget for GM effects is fulfilled and accordingly, an essential feasibility issue of CLIC has been addressed.

INTRODUCTION

CLIC [1] requires a small vertical emittance and beam size in the nanometer range to achieve its nominal luminosity. The small emittance is affected by static and dynamic imperfections. While the static imperfections will be mitigated using beam-based alignment, dynamic imperfections such as GM have to be reduced by the mechanical stabilisation systems and pulse-to-pulse beam-based feedback systems. This paper will give an overview of the status of the GM mitigation techniques proposed for CLIC. Integrated studies have been performed. More details can be found in the references.

Ground Motion

Given the tight tolerances on the quadrupole positions, the dominant luminosity degradation by dynamic imperfections is caused by technical noise, which will be mitigated to acceptable levels, and inevitable ground motion [2]. The luminosity is reduced by two effects: a beam-beam offset at the IP mainly due to the movement of the girders close to the IP and an emittance growth (filamentation) along the beamline due to offsets of the ML quadrupoles.

Phenomenological models for the GM have been developed [3] and an extensive review of the current state has been given in [4]. Two models are used in the ground model simulations, one for short time scales, and one for longer time scales ('ATL-law'). Both models include correlations in time (frequency) and space.

GM is very site-dependent and for several sites measurements have been performed to fit the model parameters, see Figure 1, where the power spectral density is shown. Three different sites have been considered in these studies. Model A is based on measurements in the empty LEP tunnel, which is a very quiet site. Model B is based on measurements on the Fermilab site. Model B10 is model B with additional peaks to match measurements from LAPP (Annecy) and the technical noise measured in the CMS hall. Other sites with even more ground motion, like model C, are not considered as it is presumed that CLIC is not able to maintain a stable luminosity.

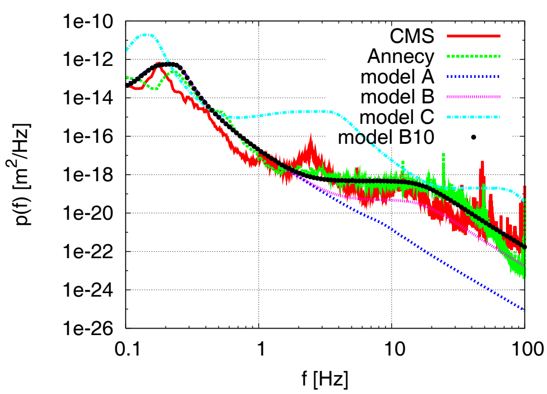

Figure 1: GM power spectral density for several sites and models.

To counter the impact of the GM several mitigation techniques are deployed in CLIC, which will be shortly summarised in the next section. Note that since the repetition rate of CLIC is 50 Hz, beam-based feedback is less effective for frequencies above a few Hz. For these frequencies other systems have to be deployed.

MITIGATION TECHNIQUES

Mech. Stabilisation System for ML and BDS

To reduce the motion of the ML quadrupoles for high frequencies ($\geq$ 1 Hz), each quadrupole will be positioned on an active stabilisation system [5]. For the integrated simulations a theoretical fit of the measured transfer functions of the current design has been used, which is shown in Figure 2. The peak at 0.2 Hz of the quadrupole stabilisation is close to the micro-seismic peak which is unfavorable. Based on the integrated simulations presented in this paper an ongoing effort has been started to obtain an improved design that has a transfer function that is more complementary to the beam-based orbit feedback (of which one is shown in the figure) in order to increase the overall performance [6]. A targeted future design is shown in the figure as well. For the BDS, the same design as for the ML has been assumed in simulation, though a more dedicated system could be envisaged.

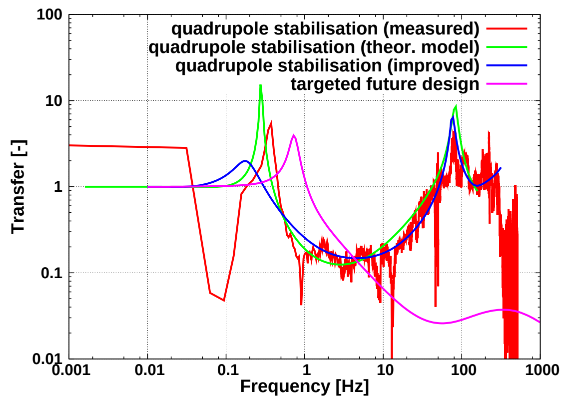

Figure 2: Amplitude of the transfer functions of the quadrupole stabilisation.

Mech. Stabilisation System for the Final Doublet

To reduce the beam offset jitter for high frequencies the final doublet system, which includes the last quadrupoles QD0 and QF1, will be put on a large mass, the preisolator [7], which is attached to the tunnel. In addition an active stabilization can be deployed, but the simulation is limited to the stand-alone usage of the preisolator. The preisolator has two support points that each have their own transfer function, which are shown in Figure 3. The resonance at 50 Hz is caused by the vibration of the cantilever and is designed to be at the beam repetition rate. For the integrated simulations these transfer functions are implemented.

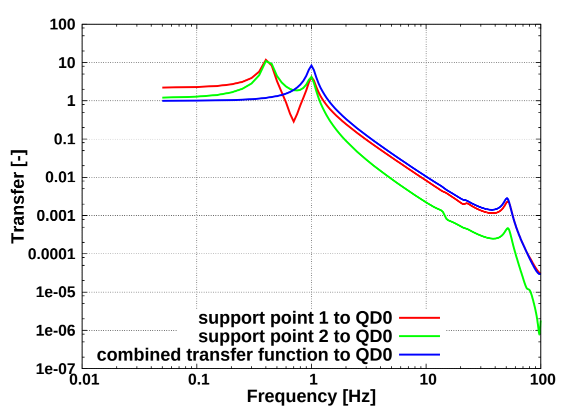

Figure 3: Amplitude of the theoretical transfer functions of the preisolator of the final doublet system.

Beam-based Orbit Controller

To correct the orbit there are two actuator options, either the quadrupoles can be moved or dipole kickers can be deployed. From an optics point of view the solutions are very similar. The current baseline for the ML is the use of quadrupole movers and dipole kickers as an alternative.

The orbit feedback system in the ML and BDS has 2122 Beam Position Monitors (BPM) and 2104 correctors to its avail. The simulated pulse-to-pulse orbit correction feedback is a global feedback based on a singular value decomposition (SVD) of the response matrix of the system with systematically adjusted weights for each singular value to reduce the noise propagation and optimise the luminosity. For a detailed description of the orbit controller, see [8].

IP Feedback

The IP feedback corrects the beam position at the IP by measuring the deflection angles of the colliding beams and adjusting the beam position with a dipole kicker positioned near QD0. An additional intra-train feedback is foreseen [9], but is not taken into account in these simulations. For a specialised IP feedback algorithm, see [10].

SIMULATION SETUP AND RESULTS

All simulations have been performed tracking the beam with PLACET [11] through the ML and the BDS, and GUINEA-PIG [12] for beam-beam interactions. All mitigation techniques have been implemented. The foreseen emittance growth budget due to the static imperfections of the transfer lines, ML and BDS combined is a growth from 5 nm normalised geometric emittance at the exit of the damping rings to 20 nm at the start of the BDS, which corresponds to a peak luminosity of about $2.4 \cdot 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Instead of integrating the static imperfections, a simplified approach is taken here. For the simulations, no static imperfections are implemented, but an emittance of 20 nm is applied at the beginning of the ML. Thus it is assumed that the whole static budget is appropriated. The foreseen budget for luminosity loss due to dynamic imperfection in the ML and BDS is about 20% of the luminosity. The nominal peak luminosity is $2 \cdot 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

Measurement errors, notably BPM noise, degrade the effectiveness of the pulse-to-pulse feedback, as a BPM measurement error will directly propagate into the orbit correction. To obtain the required BPM resolution in the BDS, simulations have been performed without other dynamic effects. In Figure 4 the relative luminosity loss is shown as a function of the BPM resolution. It can be seen that a BPM resolution of 50 nm is required in the BDS to limit the luminosity loss to 2%, while the BPM resolution in the ML can be more relaxed. The constraint on the BPM resolution can be loosened with a lower feedback gain.

In accordance to the previous result a BPM resolution of 100 nm is assumed for the ML BPMs and 50 nm for the BDS BPMs. For each of the following studies 50 machines have been simulated with different seeds.

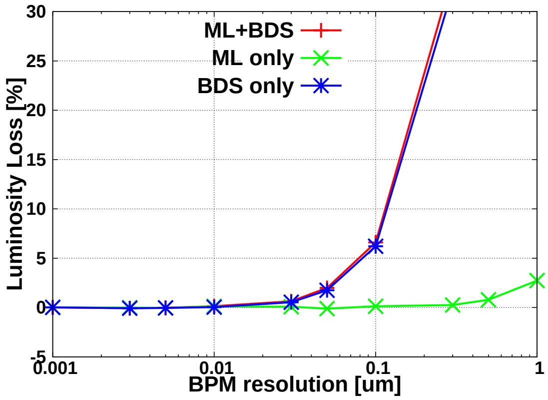

Figure 4: Relative luminosity loss as a function of the BPM resolution for the ML and BDS, separated and combined. Note that this is only due to BPM noise and that no GM has been applied.

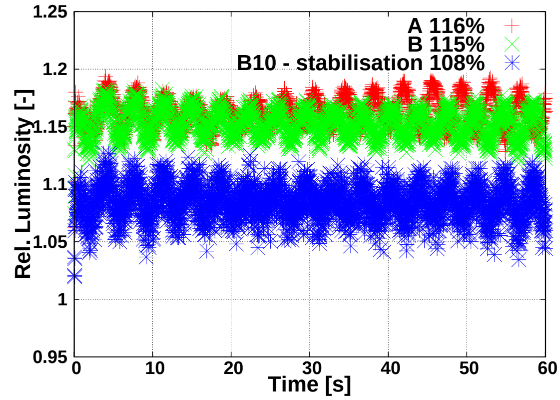

Figure 5: Average luminosity (50 seeds) for the current design over a longer time scale (60 s) for several GM models.

For the current design Figure 5 shows that the luminosity is well preserved over a long time period of 60 s, which is about the maximum time for which the used GM models are valid. The jitter on the luminosity is caused by the remaining high frequency components of the GM and the BPM resolution.

The low-frequency components are due to the difference between the transfer functions of the stabilisation of the final doublet and the rest of the beamline.

In Table 1 the relative luminosity performance for several stabilisation systems is shown. It can be concluded that depending on the GM different stabilisation measures are required. Note that for GM model A mitigation methods can even lower the luminosity performance. This is due to offsets between the preisolator and the rest of the beamline, which is caused by a difference between the two transfer functions. Note that an enhanced quadrupole stabilisation design can improve the luminosity performance significantly, see also [6].

Table 1: Relative luminosity performance (and luminosity loss in %) with respect to the nominal luminosity of $2 \cdot 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for different ground motion models and stabilisation systems.

	A	B	B10
No stab.	1.19 (2)	0.96 (25)	0.53 (68)
Preisolator only	-	1.13 (8)	0.88 (33)
Pre. + Quad. stab.	1.16 (5)	1.15 (6)	1.08 (13)
P. + Quad. stab. imp.	-	-	1.15 (6)
P. + Targ. fut. design	-	-	1.18 (3)

CONCLUSIONS

An overview of the GM mitigation techniques in the CLIC ML and BDS has been given. Mitigation techniques include the mechanical stabilisation system for the quadrupoles and for the final doublet, the beam-based orbit feedback and the IP feedback. Simulations incorporating the dynamic imperfections and mitigation techniques have been performed, where the ML and the BDS are treated as one integrated system and are simulated together. It is shown that with the current design the tight luminosity budget for dynamic imperfections, and in particular GM, is fulfilled for all studied GM models. Dependent on the actual GM different mitigation techniques can be required. Efforts are ongoing to improve all individual mitigation techniques and the interplay between them.

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