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The Clic Study of Magnet Stability and Time-dependent Luminosity Performance

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The present parameters of the CLIC study require the collision of small emittance beams with a vertical spot size of 1 nm. The tolerances on vertical quadrupole vibration (above a few Hz) are as small as a few nm in the linac and most of the Final Focus. The final focusing quadrupole has a stability requirement of 4 nm in the horizontal and 0.2 nm in the vertical direction. Those tolerances can only be achieved with the use of damped support structures for CLIC. A study has been set-up at CERN to explore the application of stabilization devices from specialized industry and to predict the time-dependent luminosity performance for CLIC. The results will guide the specification of required technological im-provements and will help to verify the feasibility of the present CLIC parameters.

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THE CLIC STUDY OF MAGNET STABILITY AND TIME-DEPENDENT LUMINOSITY PERFORMANCE

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Abstract

The present parameters of the CLIC study require the collision of small emittance beams with a vertical spot size of 1 nm. The tolerances on vertical quadrupole vibration (above a few Hz) are as small as a few nm in the linac and most of the Final Focus. The final focusing quadrupole has a stability requirement of 4 nm in the horizontal and 0.2 nm in the vertical direction. Those tolerances can only be achieved with the use of damped support structures for CLIC. A study has been set-up at CERN to explore the application of stabilization devices from specialized industry and to predict the time-dependent luminosity performance for CLIC. The results will guide the specification of required technological improvements and will help to verify the feasibility of the present CLIC parameters.

1 INTRODUCTION

The Compact Linear Collider (CLIC) study at CERN proposes an e^+e^- collider that combines a 3 TeV centre-of-mass energy, high-gradient acceleration of 150 MV/m, and a high luminosity of 10^{35} cm^{-2} s^{-1} [1]. Some important CLIC parameters are listed in Table 1. The required spot sizes in the interaction point (IP) are $\sigma_x^* = 43$ nm in the horizontal and $\sigma_y^* = 1$ nm in the vertical plane. This is below the smallest single beam size of 70 nm so far observed [2]. The SLC beams were reliably collided with a vertical spot size of 500 nm [3].

The optical design of a CLIC beam delivery section has been described for a standard [4] and short [5] version. The small IP spot sizes for CLIC and the required small beam emittances greatly enhance the sensitivity of the luminosity to imperfections [6]. Imperfections occur along the whole linac and beam delivery sections (alignment offsets, mechanical vibrations, …) and reduce the achievable luminosity in two ways:

1. Imperfections generate emittance growth $\Delta\gamma\epsilon(t)$. The required vertical IP emittance ($\gamma\epsilon^{IP} = 0.02$ mm-mrad) is small and $\Delta\gamma\epsilon(t)$ must be kept small as well (~0.005 mm-mrad). This imposes tight tolerances on the stability of transverse quadrupole positions.
2. Imperfections (mainly transverse quadrupole offsets) generate trajectory errors that are different for the two colliding beams, resulting in a time dependent beam-beam offset Δy_{IP}. The design luminosity L_0 is then reduced to a value L, which we approximate as:

$$L \approx L_0 \cdot e^{-\left[\Delta y_{IP}^2/\left(2\sigma_y^*\right)^2\right]}. \tag{1}$$

   The beam-beam offset must be a fraction of the IP spot size. This imposes stringent tolerances on the quadrupoles, with the tightest requirement occurring for the final quadrupoles.

Table 1: Some basic CLIC parameters [1].

Parameter	**Symbol**	**Unit**	**Design value**
Beam energy	E	GeV	1500
Luminosity	L	cm^{-2} s^{-1}	10^{35}
IP spot size	σ_x^*	nm	43
	σ_y^*	nm	1
Repetition rate	f_{rep}	Hz	100
Bunches/train	N_b		154
Bunch charge	N_e		$4\ 10^9$
Bunch distance	ΔT_b	ns	0.67

The values for $\Delta\gamma\epsilon(t)$ and Δy_{IP} and therefore the luminosity depend on the performance of all systems after the damping rings and cannot be studied in test facilities. They must be predicted based on the measured properties of accelerator components and detailed simulations. Most important is the time-stability of the quadrupole magnetic centres. The magnetic centre of a quadrupole in the nanometre regime is affected by the mechanical position of the overall magnet, internal mechanical deformations, and changes of the quadrupole field with fixed geometry (for example heat induced in a permanent magnet).

The CLIC stability study aims at estimating the time-stability of the magnetic quadrupole centre and at predicting the achievable luminosity, after application of correction schemes (e.g. feedbacks). For example, extending the formalism from [7], we can write the time average of the beam-beam offset Δy_{IP} as an integration over frequency ω and wave number k:

$$\left\langle \Delta y_{IP}^2 \right\rangle_t = \int_0^\infty \int_0^\infty P(\omega,k)\cdot T(\omega)\cdot G(k)\cdot F(\omega)\frac{dk}{2\pi}\frac{d\omega}{2\pi}. \tag{2}$$

Here, $P(\omega,k)$ describes the spectrum of noise like ground motion, cooling water, or heat-induced errors. $T(\omega)$ is the transfer function to the magnet (e.g. from magnet supports), $G(k)$ is the lattice response, and $F(\omega)$ is the feedback transfer function. The CLIC stability study should estimate all those functions, investigate the best available technologies (e.g. determine $T(\omega)$ for actively damped magnet supports), and predict the achievable CLIC luminosity. The final goal is to establish the feasibility of the CLIC design parameters in a realistic accelerator environment.

2 CLIC REQUIREMENTS

In the first phase of the study the requirements were reviewed for the CLIC linac and the beam delivery:

(a) Linac quadrupoles:

Number:	1300 for each of two linacs	
Field:	200 T/m	
Transverse size:	0.15×0.11 m	(width × height)
Length:	0.46 – 2.08 m	
Weight:	69 – 312 kg	
Goal:	**1.3 nm (vertical)** rms uncorrelated motion **above 4 Hz**	

(b) Final Focus quadrupoles (short or standard solution):

Number:	2			
Field:	388	or	450 T/m	
Transverse size:	4.3	or	2.0 cm	(outer radius)
Length:	3.50	or	4.75 m	
Weight:	250	or	50 kg	
Distance to IP:	4.3	or	2.0 m	
Goal:	**4.0 nm (horizontal)** **0.2 nm (vertical)** rms uncorrelated motion **above 15 Hz**			

For the linac, the estimated requirements are based on an extrapolation of the existing CLIC Test Facility quadrupoles. For the final focusing quadrupole the vibration tolerances were calculated with the program FFADA, as discussed in [4]. A permanent ring magnet was found to be the most adequate solution, in view of the very limited space, the necessary high field gradient and the stringent requirements on the mechanical stability. Figure 1 shows how the 16 premagnetized sectors will be assembled into a ring of permanent magnet material (zero clearance design). Because of its thermal stability and radiation hardness, Sm_2Co_{17} was found to be the best suited material. Field computations with ROXIE [8] showed that the required field gradient of 450 T/m is feasible. To avoid demagnetization effects, the outside field (e.g. detector solenoid field) has to stay below 2T.

The frequency requirements, as listed for the tolerable motion of linac and final focusing quadrupoles, are based on the feedback performance, that was achieved at the SLC [9]. We note that the linac quadrupoles require less stringent, but quite challenging vertical position stability, down to lower frequencies. A large number of quadrupoles must be controlled to the level of 1.3 nm.

The final quadrupoles in the beam delivery have a strict vertical stability tolerance of 0.2 nm, but above a higher frequency (faster feedback on the IP offset). Only two quadrupoles need to be controlled, but they are located inside the particle physics detector with severe mechanical constraints, mainly arising from the crossing angle [10] and the properties of the spent beam (see Figure 2).

We note, that the natural ground motion in quiet portions of the LEP tunnel was measured to be smaller than 0.2 nm above 4 Hz (accelerator off) [11]. However, levels approached 20 nm with the accelerator equipment switched on. The IP environment is known to be especially noisy, with measured motion in large particle physics detectors being in the order of a few 100 nm [12]. A proper design can improve those levels, but technical enhancement of natural ground motion should be expected and prepared for.

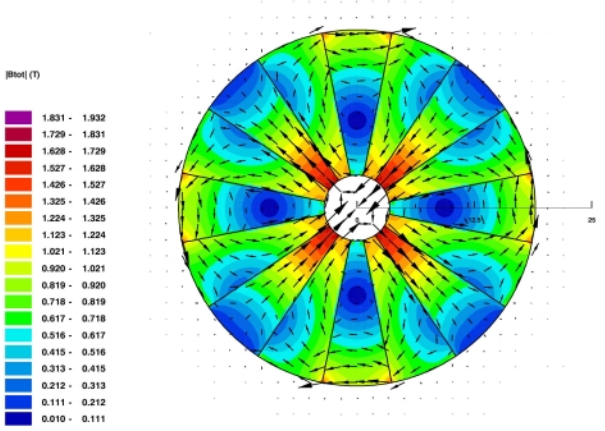

Figure 1: Cross section of the final focusing quadrupole. G=468 T/m for the permanent magnet material VACOMAX 225HR Sm_2Co_{17} (coercitivity of 820 kA/m).

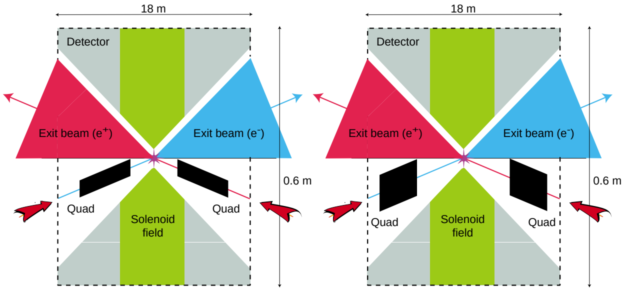

Figure 2: Top view of the CLIC IP region with the detector, the colliding beams, and the final quadrupoles for the standard (left) and short (right) beam delivery design. Crab cavities, fast kickers, beam monitors are required as well, but are not included. Scales are indicated; the transverse radius of the detector is about 17 m.

3 VIBRATION TEST STAND

A vibration test stand has been set-up at CERN. The location was required to have decent ground motion (not too noisy, not too quiet), electricity and cooling water for magnets, and sufficient space for a test set-up. The basement of a building on the CERN Meyrin site, also used for CLIC alignment studies, was selected. The room was equipped with a granite table and measurement equipment, among those two geophones (GSV-310 from GeoSig). The geophones have a frequency range from 1-315 Hz with a nominal resolution of 15.3 nm/s.

Having established the stability requirements for CLIC, the next step was to demonstrate vibration measurements with sub-nm resolution and to characterize the ground motion in our test stand. The measurements provide ve-

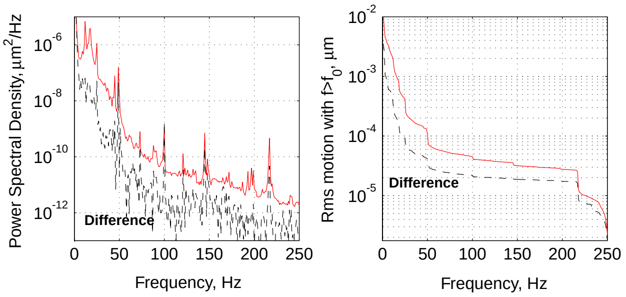

Figure 3: Power spectral density (left) and integrated rms motion above a given frequency (right), measured in the vibration test stand with two equal sensors. Shown are the absolute measurements and the difference between the two sensors for the vertical direction.

locities *v(n)*, observed at times *nΔt*, where *n* is an integer and *Δt* is the sampling time. The power spectral density with frequencies $f_k = k/(N\,\Delta t)$ for *N* measurements is then:

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

The integrated rms motion $I(f_{k0})$ above a given frequency f_{k0} is:

$$I\left(f_{k_0}\right) = \sqrt{\frac{1}{N\Delta t}\sum_{k'=k_0}^{N/2} P_d\left(f_{k'}\right)} \qquad (4)$$

An example of power spectral density and integrated motion is shown in Figure 3. More detailed measurements are described in [13]. The resolution of the available equipment was determined to be about 30 nm/s above 6 Hz. The motion of the concrete floor in the test stand was measured to have the following rms motion:

- Above 4 Hz: 5.4 nm ± 0.88 nm
- Above 15 Hz: 3.7 nm ± 0.54 nm
- Above 100 Hz: 0.1 nm ± 0.04 nm

The error is an upper estimate, based on the difference between the measurements from two identical sensors located side-by-side. We note that the concrete floor exhibits a good stability (taking account the location and industrial-like environment), which is however 5-10 times above the CLIC goal.

4 STABILIZATION TECHNOLOGY

The vibration test stand will be used to install state-of-the-art stabilization equipment from specialized industry. Mounting quadrupoles on top of the actively and passively damped tables, we will measure the magnet motion. The effect of cooling water and other accelerator supports will be quantified. At the present time, the equipment is not yet acquired. However, as a first example we studied the effect of putting rubber feet on one sensor, while connecting the other sensor directly to the supporting table. The result is shown in Figure 4, illustrating the benefit of passive damping for higher frequencies, while lower frequency perturbations are enhanced.

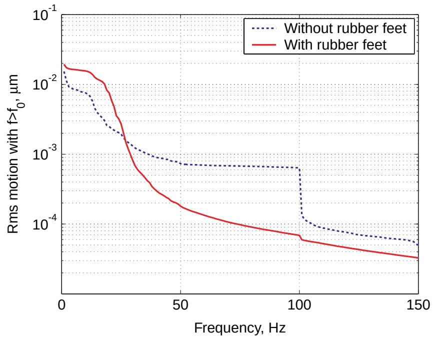

Figure 4: Integrated rms motion above a given frequency with and without rubber feet under the sensors.

5 SUMMARY AND OUTLOOK

As part of the CLIC study at CERN, we initiated a study on magnet and luminosity stability. The goal of this study is to establish the feasibility of the present CLIC design parameters, especially the collision of beams with a vertical spot size of 1 nm.

The stability study was approved in January 2001. By now, we did some preliminary magnet and IP design work, we estimated the stability requirements for the present CLIC parameters, we set-up a vibration test stand at CERN, we established vibration measurements with sub-nm resolution, and we characterized ground motion in the test stand.

To achieve a rms vertical magnet vibration of 1.3 nm above 4 Hz (linac) and 0.2 nm above 15 Hz (IP), we foresee to use modern stabilization technology. State-of-the-art equipment will be acquired and tested for usage in the environment of particle accelerators. The measured data will be put into simulations to predict the luminosity, achievable in a realistic accelerator environment.

6 REFERENCES

[1] G. Guignard (ed) *et al*, “A 3 TeV e+e - Linear Collider Based on CLIC Technology”, *CERN 2000-008*.

[2] V. Balakin *et al*, “Focusing of submicron beams for TeV Scale e+ e- linear colliders”, *Phys. Rev. Lett.* **74** (1995) 2479-2482.

[3] P. Raimondi *et al*, “Recent Luminosity Improvements at the SLC”, HEACC98. *SLAC-PUB-7955*.

[4] F. Zimmermann *et al*, “Final-Focus System for CLIC at 3 TeV”, EPAC2000, *CERN-SL-2000-057-AP*.

[5] F. Zimmermann *et al*, “Final-Focus Schemes for CLIC at 3 TeV”, HEACC2001, *CERN-SL-2001-010-AP*.

[6] R. Assmann *et al*, “Stability Considerations for Final Focus Systems of Future Linear Colliders”, *CERN-SL-2000-059-OP*.

[7] C. Adolphsen *et al*, “Zeroth-Order Design Report for the Next Linear Collider”, *SLAC Report* 474.

[8] S. Russenschuck *et al*, ”Integrated Design of Superconducting Magnets with the CERN Field Computation Program ROXIE”, ICAP2000, *CERN-LHC-Project-Report* 446.

[9] L. Hendrickson *et al*, “Beam Based Feedback Testing and Simulations for the SLC linac”, Linac2000, *SLAC-PUB-8585*.

[10] D. Schulte *et al*, “The crossing angle in CLIC”, these proceedings.

[11] V.M. Juravlev *et al*, “Seismic vibration studies for future linear colliders”, EPAC94, *CERN SL 94-41 RF*.

[12] A. Seryi, “A Shaky Road to Subnanometer Beams: NLC Ground Motion, Vibration and Stabilization Studies”, HEACC2001, *SLAC-PUB-8825*.

[13] R. Assmann *et al*, “Measuring Vibrations with Sub-Nanometer Accuracy”, to be published.