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IMPACT OF DYNAMICAL STRAY FIELDS ON CLIC

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Abstract

In this paper we estimate the tolerances of stray-fields variations on the Compact Linear Collider (CLIC), discuss possible sources and propose several solutions. The Beam Delivery System (BDS) is the most sensitive system of CLIC to unwanted magnetic field variations, already variations of 1nT would reduce the luminosity by 10% at wavelengths comparable to the BDS without considering any correction mechanism. Two sources of magnetic field variations are considered, natural and man-made. Precise magnetic field measurements at Earth's surface under a typical geomagnetic storm are presented. Additionally, stray field measurements have been conducted at CERN, to inspect B-field variations due to technical equipment in an accelerator environment. Different solutions are proposed to minimise the impact of stray fields on the CLIC performance.

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In this paper we estimate the tolerances of stray-fields variations on the Compact Linear Collider (CLIC), discuss possible sources and propose several solutions. The Beam Delivery System (BDS) is the most sensitive system of CLIC to unwanted magnetic field variations, already variations of 1 nT would reduce the luminosity by 10 % at wavelengths comparable to the BDS without considering any correction mechanism. Two sources of magnetic field variations are considered, natural and man-made. Precise magnetic field measurements at Earth's surface under a typical geomagnetic storm are presented. Additionally, stray field measurements have been conducted at CERN, to inspect $\vec{B}$-field variations due to technical equipment in an accelerator environment. Different solutions are proposed to minimise the impact of stray fields on the CLIC performance.

INTRODUCTION

The Compact Linear Collider (CLIC) [1] aims to collide e^- with e^+ at the Interaction Point (IP) at a center-of-mass equal to 3 TeV, delivering a luminosity ($\mathcal{L}$) equal to $5.9{\cdot}10^{34}$ cm^{-2}s^{-1}. The normalized emittance of the colliding beams should be equal or less than 660 nm and 20 nm in the horizontal and vertical planes, respectively. It is on the vertical plane that one finds the tightest tolerances for transporting the beam while preserving its emittance. In Ref. [2] it was found a stray field tolerance of amplitude equal to 1 nT and wavelength of few km, for different sub-systems of the machine.

Stray fields can be classified into static or dynamic. Static ones are expected to be compensated by the orbit correction schemes envisioned for CLIC, while for the dynamic variations, only the ones with frequency below 1 Hz will be attenuated by the train-to-train feedback. At frequencies above the kHz, the accelerating structures and beam pipe are expected to shield for stray fields, due to skin depth effects of copper and aluminium, respectively. In the following we present a re-evaluation of the sensitive of the BDS to stray fields using a different method. A collection of natural and man-made stray fields measurements, using a sensor with a better resolution than the one imposed by the BDS tolerances. The measurements include, the Earth's magnetic field on surface at the CLIC site location, the Earth's $\vec{B}$-field variation under a geomagnetic storm at Tihany (Hungary), and also the magnetic contamination due to technical equipments at different accelerator environments inside the CERN site.

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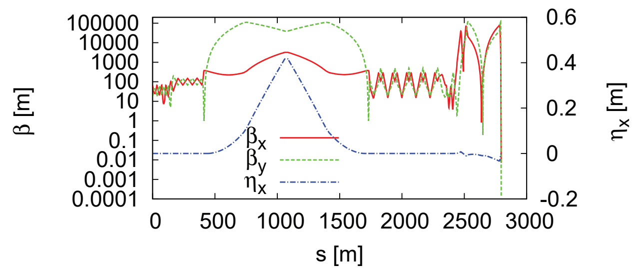

Figure 1: β_x (red),β_y (green) and η_x (blue) functions from the entrance to the end of the CLIC-BDS.

MAGNETIC FIELD TOLERANCES

The Beam Delivery Sysyem (BDS) of CLIC extends over 2.5 km and it is composed of collimation, matching, final focus and extraction sections. The collimation section extends over the first 1.5 km while the Final Focus System (FFS) takes roughly the last 500 m. The Twiss functions along the system are shown in Fig. 1, notice the two high-beta regions corresponding to the collimation and FFS.

In order to estimate the impact of the dynamic stray field, the BDS is sliced in bins of 0.1 m length. A dipole field is assigned to each bin, the strength of which, is calculated according to $A_s sin(\lambda s)$, being λ the period of the simulated $\vec{B}$-field, A_s its amplitude and s the bin position along the machine. The sin dependency will lead to a beam-beam offset at the IP (Δx_{IP}). Instead of a sin-like dependency, one could lay down $A_s cos(\lambda s)$ field leading to an angle offset at the IP ($\Delta x'_{IP}$). The relative luminosity due to position and angle offsets is evaluated according to Eq. 1 and Eq. 2, respectively.

$$\left(\frac{\Delta\mathcal{L}}{\mathcal{L}}\right)_{pos} = e^{-\frac{\Delta x_{IP}^2}{4\sigma_x^2}} \cdot e^{\frac{B^2}{A}}, \quad (1)$$

$$\left(\frac{\Delta\mathcal{L}}{\mathcal{L}}\right)_{ang} = \frac{S}{S_0}, \quad (2)$$

where,

$$A = \frac{sin^2\frac{\phi}{2}}{\sigma_x^2} + \frac{cos^2\frac{\phi}{2}}{\sigma_s^2}, \quad (3)$$

$$B = \frac{\Delta x_{IP} \cdot sin\frac{\phi}{2}}{\sigma_x^2}, \quad (4)$$

$$S = \frac{1}{\sqrt{1 + \left(\frac{\sigma_s}{\sigma_x} \cdot tan(\phi/2)\right)^2}} \quad (5)$$

being ϕ the crossing angle at the IP.

The λ parameter is scanned from 10 m to 10 km. Figure 2

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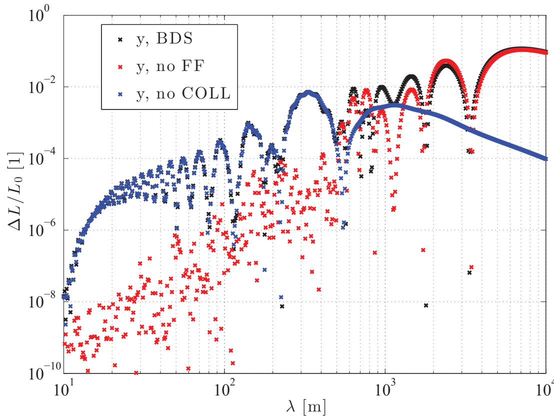

Figure 2: Relative luminosity loss against λ for stray field variations of amplitude equal to 1 nT. 3 cases are shown, no shielding (black), shielded FFS (red) and shielded collimation section (red).

shows the relative luminosity loss when assuming a stray field *sin*-like of amplitude equal to 1 nT for 3 scenarios; no shielding, shielded FFS or shielded collimation section. The $\mathcal{L}$ loss due to stray fields has two important sources, the collimation section contributes at larger values of λ ($\geq$ *km*), whereas the FFS becomes important for shorter values ($\leq$ *km*), as shown in Fig. 2. The maximum $\Delta\mathcal{L}$ loss, is about 12 % for λ=7 km. However when the collimation section is shielded the maximum $\Delta\mathcal{L}$ loss is almost 10 % at λ=300 m. Regarding the impact of position and angle offset, it is found that the luminosity loss due to angle offset (*cos*-like) is one order of magnitude less severe than the one obtained by position offset (*sin*-like), see Ref. [3].

MEASUREMENTS

Natural and man-made stray fields measurements are presented in this section. Several measurements have been conducted at CERN to exemplify the level of magnetic field contamination due to technical equipment. A brief description of the sensor used for measuring is given below.

Instrument

The sensor employed in the measurements is the Lemi-035 [4]. It is a flux gate magnetometer sensitive from sub-nT to few μT. The observable frequency range is limited by the 128 Hz sampling rate and the filter cut-off at 20 Hz, which may not be adequate to measure $\vec{B}$-field variations due to technical equipment present in an accelerator. The sensor is not radiation hazard so it cannot be in the vicinity of a running accelerator.

Natural Fields

One possible natural magnetic field variation above the nT regime are geomagnetic storms. Figure 3 shows the Earth's magnetic field variation under the influence of a typical geomagnetic storm. The measurement took place

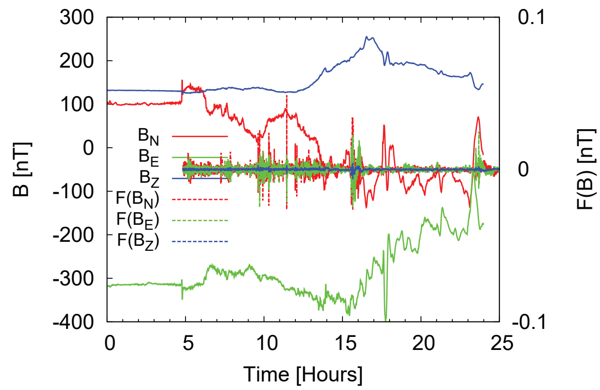

Figure 3: Variation of Earth's B_N, B_E, B_Z-field components in solid red, green and blue respectively, under a geomagnetic storm observed at the Tihany (Hungary). The expected $\vec{B}$-field (dash lines after applying the orbit feed-back ($F(B)$).

at Tihany (Hungary) (comparable latitude as Geneva). The maximum variation is of few hundreds of nT, however a severe storm [5] can reach variations up to few $\approx$ μT. These extreme storms occur occasionally and their arrival to the Earth can be predicted. Another source are Geomagnetic pulsations (ULF) [6] which can also produce variations in the nT range. The maximum variation of $\vec{B}$-field per second is of a few nT. In both cases the orbit feed-back should be capable of compensating for this variation, as CLIC operates at 50 Hz. To this end, the geomagnetic data has been filtered with the corresponding CLIC orbit feed-back [7]. The standard deviation of the filtered data is reduced to few tens of pT, a reduction factor $\geq 10^3$. The filtered data ($F(B)$) is shown on the right vertical axis of Fig. 3.

The magnetic disturbance is quite homogeneous at the Earth's surface, but the inductive response depends on the local geology and inbuilt materials which in turn breaks its homogeneity. The same is valid for wave propagation. Measurements underground would be required to better understand all these effects.

Technical Equipment Fields

We have measured the $\vec{B}$-field variations at 2 different accelerator environments, the CLIC Test Facility (CTF3) [8] and the X-band high RF power test-stand XBOX-3. An additional measurement outside CERN site and close to the CLIC one was also recorded.

A portion of the measurement carried out at CTF3 is shown in Fig. 4 (red), an extended version can be found in [9]. The observed variation is $\geq$ 2 μT as the range of the sensor was repeatedly exceeded. Because of the signal periodicity, it was suspected that the Proton Synchrotron [10], located a few tens of meters away, was the source of this unexpected signal. Indeed, when comparing the magnetic cycle of the synchrotron with the measurement, a clear correlation is observed, as shown in Fig. 4.

The XBOX-3 test-stand is conceived to test the breakdown rate of the CLIC accelerating cavities. The cavities are fed

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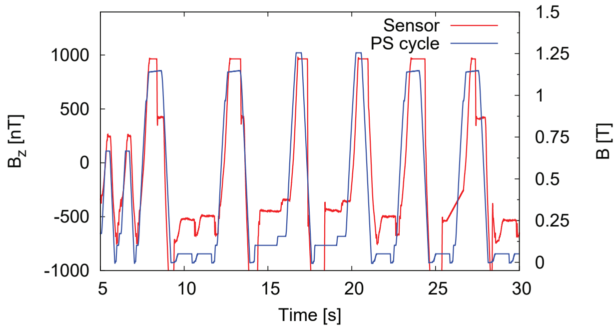

Figure 4: Comparison between $\vec{B}$-field variation recorded by the sensor (red) and the magnetic cycle of the Proton Synchrotron (blue) at CERN.

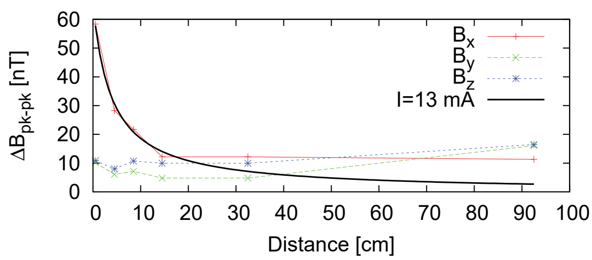

Figure 5: Peak to peak $\vec{B}$-field variation ($\Delta\vec{B}_{pk-pk}$) at different distances from the waveguide. Analytical model (black) of $\vec{B}$-field variation induced by an infinite current of 13 mA going through the waveguide.

by the waveguides coming from the klystrons. The sensor was initially placed 0.5 cm below one of the waveguide. A peak-to-peak $\vec{B}$-field variation (ΔB_{pk-pk}) of almost 60 nT was observed, with the same frequency as the klystron and modulator were operating at that moment. Changing the frequency of the klystron did also change the frequency of the signal, and even if there was no power feeding the cavities the field variation remained present. Therefore either the klystron and/or modulator need to be better grounded in order to avoid any current leaking through the waveguide. A current of 13 mA going through the copper-waveguide would explained the observed measurement. The signal is rapidly attenuated, when moving the sensor away from the waveguide, as Fig. 5 shows. Alternatively, the recorded signal was effectively attenuated when shielding the sensor by a cylinder-shape sheet of soft-μ magnetic material, as shown in Fig 6. The material is an Iron-Nickel alloy with very high permeability in weak magnetic fields, more details can be found in [11].

The $\vec{B}$-field has been measured at Thoiry, a small village outside CERN (accelerator-free environment), close to where CLIC is expected to be built. The measurement last for a couple of hours and the recorded $\vec{B}$-field variation were of the order of few nT. Looking at the frequency spectra few peaks become clear, as shown in Fig. 7. The peak observed at ≈16.7 in all 3 components correspond most probably to the railway electrification system adopted in Switzerland.

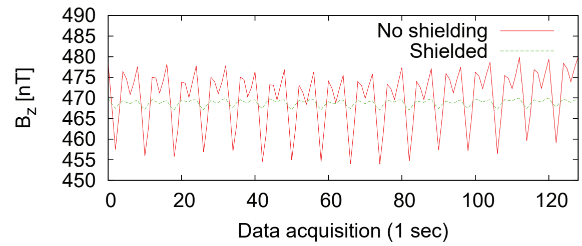

Figure 6: Peak to peak $\vec{B}$-field variation ($\Delta\vec{B}_{pk-pk}$) when shielding (green) and without shielding (red) the sensor.

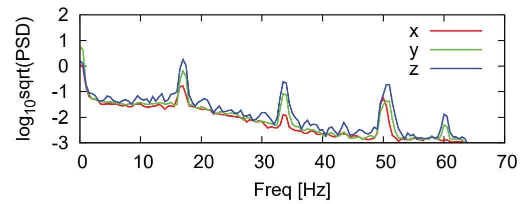

Figure 7: Frequency spectra of recorded signal in Thoiry.

This value is slightly above the 50/3 Hz to avoid over-heating the grid. The peak at around 33.6 Hz is a multi-harmonic of the 16.7 Hz.

CONCLUSIONS

Stray field tolerances of the order of nT are found for the CLIC BDS, unfortunately natural (i.e. geomagnetic storms) and man-made sources are well above that tolerance. Geomagnetic storms change the Earth's magnetic field by few hundreds of nT, although the variation is slow enough for the beam-based feedback to correct for. This is not the case for the technical equipment present in accelerator environment. It has been shown that the Proton-Synchrotron induces a $\vec{B}$-field variation of the order of μT over a few meters from the ring. Also the waveguides feeding the accelerating cavities induce variations of few tens of nT. Therefore active and passive counter-measures need to be considered for minimizing the impact of stray fields on the CLIC BDS performance. It has been shown that soft-μ magnetic material can act as passive shielding as it effectively absorbs variations of few tens of nT for intermediate frequencies. The collimation section of the BDS is the recommended location of passive shielding, if shielding the entire system is not possible. An active compensation, as the one used at LIPSION [12], is currently under development at CERN. To this end, additional sensors are required to characterize the propagation of $\vec{B}$-field variation in space. Moreover underground measurements are in need to design a magnetic feed-back system that effectively corrects for stray fields.

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