DYNAMIC EFFECTS IN THE NEW CLIC MAIN LINAC

D. Schulte*, R. Tomas, CERN, Geneva, Switzerland

Abstract

In the compact linear collider (CLIC) the tolerances on dynamic imperfections are tight in the main linac. In particular the limited beam delivery system bandwidth requires very good RF phase and amplitude stability. Transverse motion of the beam line components is also of concern. The resulting tolerances are detailed in the paper for the CLIC main linac lattice [1].

INTRODUCTION

Dynamic imperfections in the CLIC main linac can significantly impact the luminosity. Strong focusing is required to avoid that transverse jitter of the incoming beam leads to beam break-up, this requires a large number of strong quadrupoles. Transverse jitter of these quadrupoles will kick the beam and can reduce the luminosty. Active stabilisation of these quadrupoles is required together with beam-based orbit feedback. Jitter of the phase and amplitude of the accelerating RF can lead to emittance growth due to residual dispersion in the main linac. In addition, the resulting energy errors can lead to luminosity loss since the beam delivery system bandwidth is limited.

In the following the emittance growth due to element jitter is studied first and the conceptual orbit feedback will be described. Then the impact of RF jitter is detailed. All the simulations presented in this paper are performed using PLACET [2] for beam tracking. Luminosities are obtained feeding the beams at the interaction point into GUINEA-PIG [3].

BEAM JITTER

Transverse jitter of the beam entering the main linac can in principle lead to single- or multi-bunch beam break-up. The multi-bunch effect is discussed elsewhere [4]. The single bunch beam break-up is suppressed by application of BNS damping.

BEAM LINE ELEMENT JITTER

The impact of transverse jitter of the beam line elements is studied first. The luminosity loss associated with this effect can be described by the multi-pulse emittance growth in the main linac. This is the projected emittance of a number of consecutive beam pulses. The luminosity loss due to an emittance growth of $0.4\,\mathrm{nm}$ depends on the final beam emittance, 2% for a well corrected machine with a final emittance of $10\,\mathrm{nm}$ and 1% for a machine just at the target of $20\,\mathrm{nm}$. It is assumed that all elements of one type jitter indepently of the other elements and that the jitter spectrum corresponds to white noise, i.e. that the elements jitter around a central position. As can be seen in table 1, the quadrupole jitter needs to be limited to the nano-meter range and that of the accelerating structure to the micrometer range.

Table 1: The element position and angle jitter each leading to a multi-pulse emittance growth of $0.4\,\mathrm{nm}$.

Element type	offset	angle
Quadrupole	$1.8\,\mathrm{nm}$	$170\,\mathrm{nradian}$
Acc. structure	$2.8\,\mu\mathrm{m}$	$1.4\,\mu\mathrm{radian}$

ORBIT FEEDBACK

The orbit feedback consists of 40 corrector stations and 41 orbit measurement stations. In each corrector station two quadrupoles are moved to modify the beam orbit; they are seperated by about 72° phase advance. In each measurement stations eight beam-position monitors (BPMs), located in front of consecutive focusing quadrupoles, are used to measure the beam orbit. The corrector stations are placed in the centre between two consecutive measurement stations.

The quality of the correction that can be achieved with this layout has been investigated. In one case, the beamline has first been subjected to $1000\,\mathrm{s}$ of ground motion modeled according to the ATL-law with a value of $A = 0.5\times10^{-6}\,(\mu\mathrm{m})^2/(\mathrm{ms})$. In the other case, an RMS drift of the quadrupoles of $100\,\mathrm{nm}$ has been assumed. In both cases the feedback has then been applied until convergence has been reached. The final residual emittance growth is shown in Fig 1. In case of ATL motion and $N_f = 40$ feedback stations, the emittance grows with a rate of $0.2\,\mathrm{nm}/1000\,\mathrm{s}$. Consequently, more complex corrections need to be performed on a roughly hourly timescale. This can be done using one-to-one steering, which leads to a residual emittance growth rate of about $1\,\mathrm{nm}/10^5\,\mathrm{s}$.

While reducing the quadrupole induced dynamic emittance growth, the feedback will also induce an additional emittance growth due to the BPM resolution. As can be seen in Fig. 2 this emittance growth does not depend on the number of feedback stations.

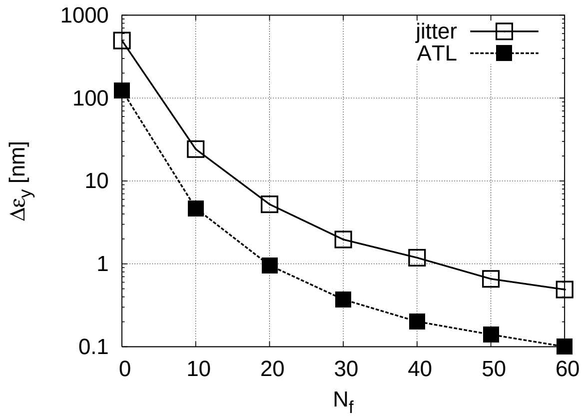

Figure 1: The residual emittance growth after $1000\,\mathrm{s}$ of ATL-type ground motion and of RMS quadrupole drifts of $100\,\mathrm{nm}$, respectively.

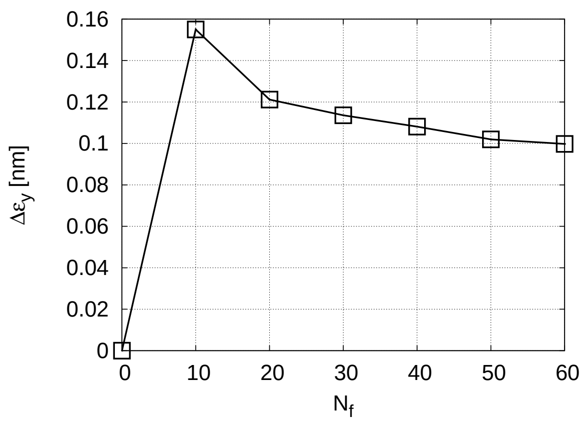

Figure 2: The multi-pulse emittance growth if the feedback runs at full gain for a BPM resolution of $100\,\mathrm{nm}$.

RF JITTER

The beam is accelerated with an average RF phase of about 12°. Consequently a phase jitter of $\Delta_\phi = 0.1^\circ$ leads to an effective gradient error of 3.6×10^{-4}. The RF phase is not constant along the linac. Over the main part a phase typically smaller than 12° is used to provide a correlated energy spread in the beam for BNS damping. At the end of the linac a phase of 30° is used in order to compress the beam energy spread to the target RMS value of 0.35%. Hence phase jitter in the end of the linac will impact the beam energy more than at the beginning.

Jitter of the drive beam current or phase in the decelerators will lead to jitter of the amplitude or phase of the RF that accelerates the beam in the main linac. This will lead to energy errors of the main beam along the linac, which in turn can lead to luminosity loss via two main effects. First, the energy bandwidth of the beam delivery system is limited, see Fig. 3. Hence, an energy jitter of the beam entering the beam delivery system will lead to luminosity loss. Second, the beam energy error along the linac can

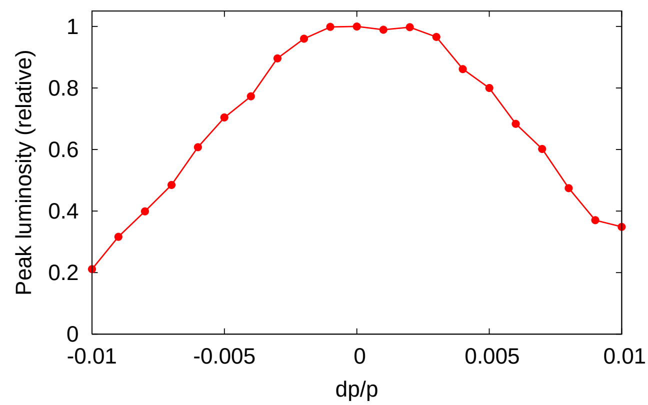

Figure 3: Energy bandwidth of the beam delivery system.

lead to emittance growth which then leads to an increased beam size at the interaction point and hence to luminosity loss.

First, only the impact of the limited beam delivery system energy bandwidth is studied. It is assumed that main linac and beam delivery system are perfectly aligned. The beam emittance at the entrance of the linac is adjusted to obtain the correct luminosity at the collision point for nominal conditions. In the simulations, the RF phases and amplitudes are then varied independently and randomly in the electron and positron linac and four types of errors are considered:

- An RF phase error $\sigma_{\phi,coh}$ of constant size along the whole main linac.
- An independent RF phase error $\sigma_{\phi,inc}$ for each drive beam decelerator of the linac.
- An RF amplitude error $\sigma_{G,coh}$ of constant size along the whole main linac.
- An independent RF amplitude error $\sigma_{G,inc}$ for each drive beam decelerator of the linac.

The results of the simulations for coherent errors along the main lianc are shown in Figs. 4 and 5. The luminosity loss can be approximated as

$$\begin{aligned}\frac{\Delta\mathcal{L}}{\mathcal{L}} &\approx 0.01\left[\left(\frac{\sigma_{\phi,coh}}{0.2^\circ}\right)^2+\left(\frac{\sigma_{\phi,inc}}{0.8^\circ}\right)^2\right.\\ &\left.+\left(\frac{\sigma_{G,coh}}{0.75\cdot 10^{-3}G}\right)^2+\left(\frac{\sigma_{G,inc}}{2.2\cdot 10^{-3}G}\right)^2\right] \quad (1)\end{aligned}$$

The tolerance for the incoherent error is three to four times as large as for the coherent error. The required stability of RF phase and amplitude is quite tight and translates into stringent requirements for the drive beam phase and amplitude. However, compared to the tolerances for previous versions of the beam delivery system [5] the tolerances are significantly relaxed. This is a very beneficial result of the increased bandwidth of that system.

Also the increase of the beam emittance due to RF jitter can lead to luminosity loss. This is particularly important

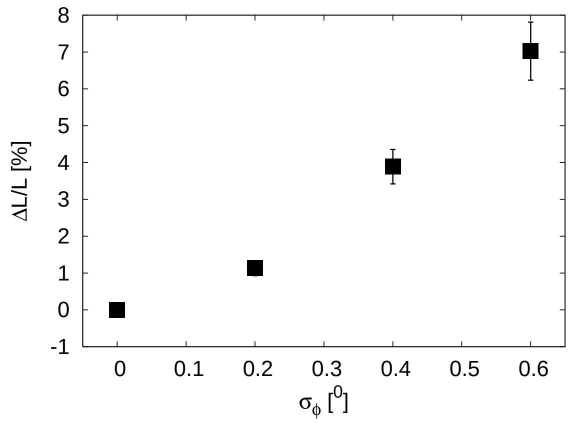

Figure 4: The relative luminosity loss for a perfectly aligned machine as a function of the coherent RF phase jitter.

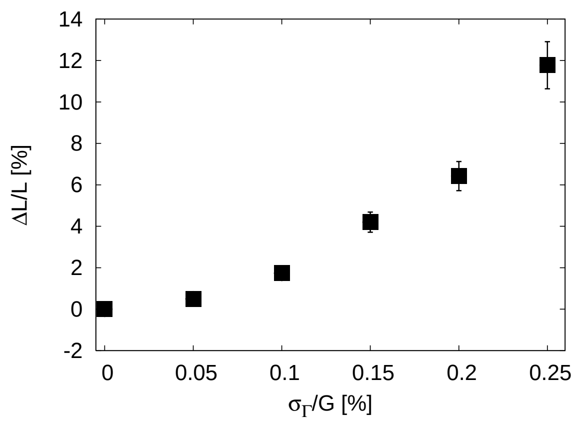

Figure 5: The relative luminosity loss for a perfectly aligned machine as a function of the coherent RF amplitude jitter.

in case that spurious dispersion has built up. To evaluate this, the main linac has been simulated with an initial emittance of 10 nm. The initially perfect machine has been subjected to 10^6 s of ATL like ground motion and a one-to-one steering has been performed. This yields an average total emittance of about $20\,\mathrm{nm}$ at the end of the main linac, which corresponds to the nominal target emittance. The emittance growth due to RF jitter is shown in figures 6. An emittance growth of $0.4\,\mathrm{nm}$ is expected to lead to a luminosity loss of 1%. As can be seen, this corresponds to a coherent phase jitter of $0.3°$, which is comparable to the corresponding tolerance for energy related luminosity loss. The situation is similar for coherent gradient jitter. Also for incoherent phase and gradient jitter the tolerances for the two mechanisms are very similar.

Further study will be needed to explore potential mitigation techniques that can reduce the RF jitter induced emittance growth. Methods may for example be to introduce one dispersion correction knob per decelerator.

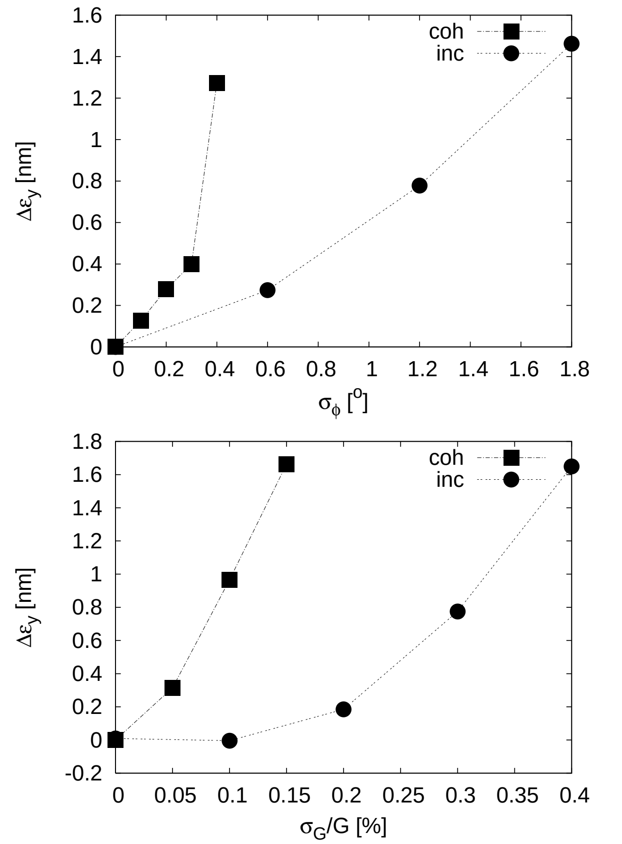

Figure 6: The sensitivity of the CLIC main linac to RF jitter after 10^6 s of ground motion and one-to-one correction.

CONCLUSION

The emittance growth resulting from quadrupole and structre jitter in the new CLIC main linac has been evaluated. The quadrupoles need to be stabilised to the nanometer level while the tolerances for the structures are significantly more relaxed.

RF phase and amplitude jitter of significant concern for CLIC. However, the energy bandwidth of the beam delivery system has substantially increased. This significantly relaxes the phase and amplitude tolerances for the drive beam.

REFERENCES

[1] H. Braun et al. "CLIC 2008 Parameters", CLIC Note 764 (2008).

[2] A. Latina et al., "Recent Improvements in the tracking code PLACET", EPAC 2008.

[3] D. Schulte, "Study of Electromagnetic and Hadronic Background in the Interaction Region of the TESLA Collider", TESLA-97-08 (1996)

[4] D. Schulte, "Multi-bunch calculations in the new CLIC main linac", this conference.

[5] D. Schulte et al. "The impact of longitudinal drive beam jitter on the CLIC luminosity", CLIC-Note-598 (2004)