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FEEDBACK RESPONSE IN THE CLIC MAIN LINAC TO TRANSVERSE AND LONGITUDINAL DYNAMIC IMPERFECTIONS

N. Leros, D. Schulte

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N. Leros, D. Schulte, CERN, Geneva, Switzerland

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In the main linac of the Compact Linear Collider (CLIC), longitudinal and transverse dynamic imperfections, such as RF phase jitter, variation of bunch length and movements of elements, can result in significant luminosity loss. The responses of local trajectory feedbacks to these imperfections are studied in this paper.

1 INTRODUCTION

In the main linac of CLIC, trajectory feedbacks will be used to reduce the emittance growth and luminosity loss due to dynamic effects. In practice, several local trajectory feedbacks along the linac will re-steer the beam back to the reference trajectory. The purpose of this paper is first to study the feedback responses and the emittance growth in the frequency domain due to transverse excitations for different feedback configurations. Next, results concerning the spectral emittance growth due to quadrupole vibrations are given. Other dynamic imperfections will also be investigated, such as RF phase and bunch length variations which may affect the feedback performances and change the feedback spectral response.

The results concerning these studies have been obtained by using PLACET [1]. The simulations have been performed with a single bunch beam containing 4×10^9 particles, assuming a repetition frequency of 100 Hz. The bunch has no energy dispersion and its length is 35 μm. The vertical emittance is ϵ_y = 5 nm at the entrance of the linac. Only results concerning the vertical emittance are presented.

2 FEEDBACK PARAMETERS

In our simulations, a feedback is able to measure the beam offset and to calculate the correction to apply in order locally to re-steer the beam back to the reference beamline. The feedbacks consist of 2 dipole correctors, placed in two consecutive vertically focusing quadrupoles, and 3 beam position monitors (BPMs) with a resolution of 100 nm. The first BPM is in front of the second feedback quadrupole and the 2 other BPMs in front of the next two vertically focusing quadrupoles. The BPMs define the beam angle and position offsets. The dipoles correct only a fraction g (the gain) of the calculated correction.

We will consider 2 kinds of feedbacks. First, to keep the emittance growth small, a chain of feedbacks along the linac will operate at a gain g_1. Secondly, the feedback at the IP is considered through a simple model. For that, a feedback which is independent of the previous chain steers the beam back to the reference beamline. It operates with a higher gain g_2 and only 2 BPMs are used to monitor the beam angle and position.

In the linac, the feedbacks of the chain can be independent, which means they do not exchange information. In another feedback configuration, N feedbacks can also be dependent. In this case, they constitute a bin of length N, where all the feedbacks of the bin communicate. A chain of k independent feedback bins, each made of N feedbacks, can also be implemented along the linac.

The feedback device configuration for the present simulation is based on 40 feedbacks in the linac and 1 feedback at the IP. In principle, the number of feedbacks and the gain optimisation settings depend on the noise spectrum. For example, it has been shown that for a ground motion described by the ATL model [2] with A=0.5×10^{-6} (μm)^2/(sm), 40 independent feedbacks in the linac minimise the emittance growth for a gain g_1 of 0.02. For the present studies, adopting g_1=0.01 and g_2=0.3 was found to be a reasonable choice.

3 EMITTANCE AND FEEDBACK RESPONSE CALCULATION

Due to the dynamic imperfections, the beam is disturbed in the linac. When feedbacks operate, the beam is corrected. We consider disturbed and corrected beams composed of L slices at the end of the linac. A beam pulse is made of N_b particles and the slice l has N_l particles. Each beam pulse p occurs at some time t. We define for each slice l the position $y_l(t)$ and the angle $y_l^{'}(t)$, which are functions of the time. The fraction of the beam particles inside the slice is w_l=N_l/N_b. The corresponding Fourier transforms of $y_l(t)$ and $y_l^{'}(t)$ are given by $F[y_l](f)$ and $F[y_l^{'}](f)$. For $F[y_l](f)$, we define the real part $F_r[y_l](f)$ and the imaginary part $F_i[y_l](f)$, with similar definitions for $F[y_l^{'}](f)$.

The emittance at the pulse p, i.e. at some time t, is computed by :

$$\epsilon(t) \propto \sqrt{\sum_j^L w_j\,(y_j(t))^2 \sum_k^L w_k\,(y_k'(t))^2 - \left(\sum_l^L w_l y_l(t) y_l'(t)\right)^2}$$

For a single mode with frequency f, the time dependent evolution of the emittance is $\epsilon(t) \propto sin^2(2\pi f t)$. In order to average the emittance over 1 total oscillation for each considered mode of our spectrum, the emittance in the frequency domain $F[\epsilon](f)$ is computed from the Fourier transform function as follows :

$$
\begin{aligned}
F_{r,i}[\epsilon](f) &\propto \{\sum_j^L w_j \left(F_{r,i}[y_j](f)\right)^2 \sum_k^L w_k \left(F_{r,i}[y_k^{'}](f)\right)^2 \\
&- \left(\sum_l^L w_l F_{r,i}[y_l](f) F_{r,i}[y_l^{'}](f)\right)^2 \}^{\frac{1}{2}} \\
F[\epsilon](f) &= \frac{1}{2}\left(F_r[\epsilon](f) + F_i[\epsilon](f)\right)
\end{aligned}
$$

The power spectral density (PSD) of the emittance is defined as :

$$P[\epsilon](f) = \sqrt{F_r[\epsilon](f)^2 + F_i[\epsilon](f)^2}$$

We will consider the spectral emittance $F[\epsilon](f)$ for the corrected beam and the response function of the feedbacks $P[\epsilon](f)_{cor.}/P[\epsilon](f)_{dist.}$, obtained from the corrected and disturbed beams.

4 FEEDBACK CONFIGURATION

In this section, we compare the feedback response for different feedback configurations. As explained above, forty-one feedbacks are used. The first 40 feedbacks are organised into k groups, each of them containing N dependent feedbacks. The following cases are investigated :

- 40 independent feedbacks (k=40 and N=1)
- 10 groups (k=10), 4 dependent feedbacks in each group (N=4).
- 4 groups (k=4), 10 dependent feedbacks in each group (N=10).
- 1 single group (k=1), 40 dependent feedbacks in one group (N=40).

We simulate an incoming beam jitter of 1 μm at the entrance of the linac. It is a single beam step disturbance. The feedbacks need some time to compensate for this instantaneous perturbation.

The response function of 40 independent feedbacks (Fig. 1) shows a huge amplification effect between 0.25 Hz to 1.4 Hz. The behaviour of the response function comes from the competition of the IP feedback with the linac feedbacks. The spectral emittance growth, as seen at the bottom of the same figure, is huge around 0.8 Hz within a bandwidth of about 1 Hz. We also see that the correction is effective below 0.2 Hz.

Going to a configuration with less independent feedbacks, we first see that the amplification becomes much smaller, as shown in Fig. 2 for 10 groups (k=10). The damping now occurs at lower frequency ($\leq$ 0.1 Hz). In the case of k=4 (N=10), we see that there is no longer an amplification and the response function is damped below $\approx$ 0.5 Hz. The damping becomes more and more effective when the feedbacks are settled into more groups. For

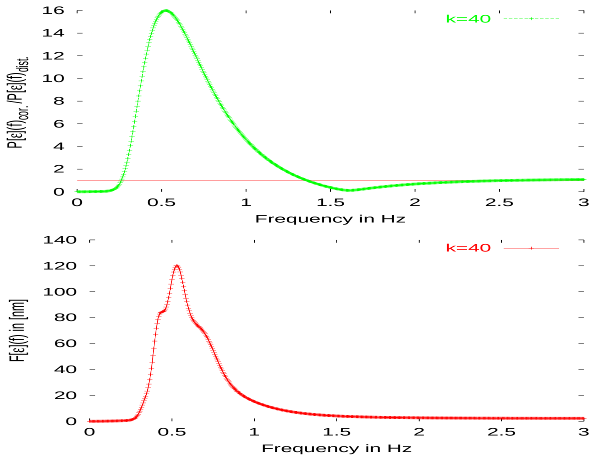

Figure 1: Feedback response and emittance growth due to the 1μm incoming beam jitter for 40 independent feedbacks.

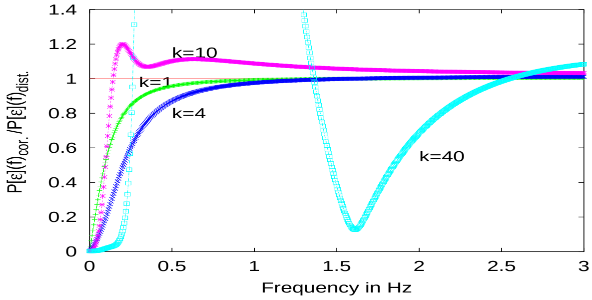

Figure 2: Feedback response to the 1 μm incoming beam jitter for different feedback configurations.

a single group configuration where all the feedbacks communicate, the excitation due to the pulse offset is damped below $\approx$ 1 Hz.

The resulting emittance growth in the frequency domain is shown in Fig 3. When the amplification effect is avoided, the emittance growth is damped below $\approx$ 1 Hz.

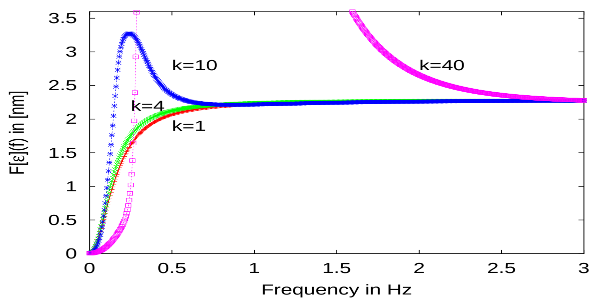

Figure 3: Emittance growth in the frequency domain due to the 1 μm incoming beam jitter for different feedback configurations.

5 EMITTANCE GROWTH DUE TO QUADRUPOLE JITTERS

All the quadrupoles of the linac are set in motion in the whole frequency range (0-50Hz) with a very small amplitude of 1 nm. For this, 500 frequency modes are used. The excitation phases vary randomly from mode to mode and from quadrupole to quadrupole. In order to get some statistics, we consider five different machines. The investigated configuration consists of 40 feedbacks in a single group (g_1=0.01). For a given machine, we simulate 2500 pulses. Comparing the plots of Fig. 4, we see that the time evolution of the emittance growth starts to be periodic after 180 pulses. In order to avoid aliasing problems in the Fourier analysis and to get the feedback reponses in a stable regime, we consider for each machine the pulses 1500 to 2500.

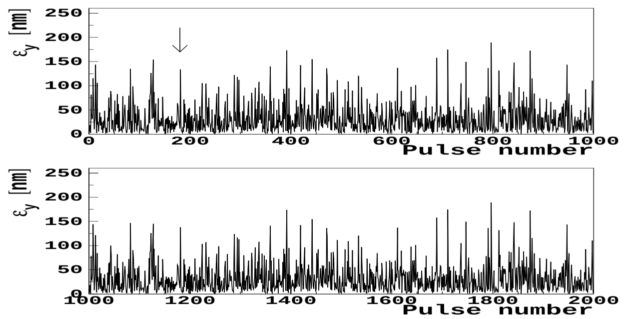

Figure 4: Emittance growth during 2000 pulses when the feedbacks are switched on during quadrupole jitters. Single group configuration consisting of 40 feedbacks.

The response function for the 5 machines are very similar to the corresponding one in Fig. 2. The average spectral emittance F[ϵ] per frequency mode, for a amplitude quadrupole jitter of 1 nm, is shown in Fig. 5. Above 1 Hz, the expected emittance for a single mode is 0.12 nm, which is an emittance growth of 2.4 %.

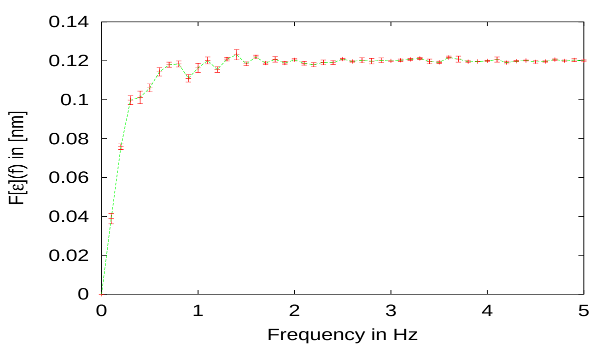

Figure 5: The average spectral emittance (in nm) by frequency mode for a quadrupole jitter amplitude of 1 nm. Single group configuration for the 40 feedbacks.

6 RF PHASE AND BEAM LENGTH VARIATION

We have seen that using communicating feedbacks helps to reduce the emittance growth due to transverse excitations in the low frequency range. For this, we have to calculate the transport matrices between the feedbacks which are in the same group. Longitudinal dynamic effects change the transport matrix between two feedbacks and then affect the feedback correction. Here we evaluate the emittance growth induced by bunch length and RF phase variation for the configuration of a single group defined previously. The linac is pre-aligned through the complete procedure described in [3].

The drive beam linac is composed of 22 decelerating sections, which provide the power in the RF structures. The RF phase can vary separately in each drive beam decelerator from pulse to pulse. We consider that the RF phase follows a normal distribution around its nominal value with σ=1°. We simulate 500 pulses with and without RF phase variation. To avoid the transient regime, the Fourier analysis is performed after the pulse 400. We compute the emittance growth of 100 pulses taken as a whole. The emittance growth due to the RF phase variation is 4.7 %.

PLACET has been modified in order to simulate bunch length variation from pulse to pulse. We assume that the bunch length follows a flat distribution from 30 to 40 μm. The analysis is done as above. In this case, the emittance growth is 1.3 %.

7 CONCLUSION

In this paper we have studied the feedback response to dynamic transverse imperfections. Different feedback configurations have been studied, composed of 40 feedbacks along the linac and one separate feedback at the IP. For a configuration with the 40 communicating feedbacks along the linac, the emittance growth is reduced for excitation frequency modes below 1 Hz. Then, we have seen that the emittance per mode for 1 nm quadrupole jitter gives an emittance growth of 2.4 % above 1 Hz. Below this frequency, the studied feedback configuration damps the vibration effects. Finally, the effects on this feedback configuration correction of RF phase and beam length variation have been investigated. We have found that these longitudinal imperfections contribute by an emittance growth of 4.7 % and 1.3 % respectively. These studies provide a basis to further optimisations of the feedback configuration for different noise spectra.

8 REFERENCES

[1] E.T. d'Amico, G. Guignard, N. Leros, D. Schulte, Simulation Package based on PLACET, CERN/PS 2001-028(AE) and PAC01.

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