SIMULATION OF PHASE STABILITY AT THE FLAT TOP OF THE CLIC DRIVE BEAM

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Abstract

The drive beam phase stability is one of the critical issues of the Compact Linear Collider (CLIC). In this paper the generation and propagation of drive beam phase errors is studied for effects that vary during the drive beam pulse. This includes the influence of drive beam current and phase errors as well as of drive beam accelerator RF phase and amplitude errors on the drive beam phase after the compressor chicanes and the analysis of the propagation of these errors through the drive beam combination scheme. The impact of the imperfections on the main beam is studied including the possible correction with help of a feedforward system.

INTRODUCTION

The Compact Linear Collider (CLIC) is a proposed multi-TeV e+ e- collider based on two-beam technology: The Drive Beam is used to deliver RF power for the accelerating structures of the Main Beam. Hence, the stability of the Drive Beam is of crucial importance for the construction of CLIC. The tolerances for many parameters of the drive beam are very strict, e.g. for drive beam accelerator RF power 0.2%, for RF phase 0.05°, for the bunch charge 0.1% and for the bunch phase 0.2° at 1 GHz (175 μm), considering a feedforward which is supposed to reduce the phase jitter by the factor of 10 [1].

The drive beam jitter of the bunch charge and phase contribute quadratically to the luminosity loss [1]. Furthermore, the error of the bunch length causes an error of the bunch form factor, and in order to maintain the same accelerating gradient the bunch charge must be increased. This consequently leads to further luminosity loss.

The presented study is the result of modeling of the error propagation through the drive beam from the klystrons to main beam accelerator and the impact of these errors on the main beam parameters.

DRIVE BEAM SCHEME

To operate CLIC at 12 GHz frequency, ~240 ns long pulses are needed [2]. This cannot be provided by any conventional RF source, so another solution has been chosen: the RF power is provided by a drive beam. This method has the advantage of lower losses when transporting the beam pulses and compressing them to high ratios.

The drive beam is produced using the standard RF sources at frequency of only ~0.5 GHz. The frequency is afterwards multiplied by a factor 2 in a delay line, and by factors 3 and 4 in the two following combiner rings, hence giving the drive beam at the 0.213 m long PETS the frequency of (0.5 GHz) $\times 2 \times 3 \times 4 \approx 12$ GHz. The frequency multiplications are designed in the following way: the bunches arriving at the delay loop have a frequency of 0.5 GHz, and they are gathered in 240ns long trains, which have a relative phase shift of 180° (Fig. 1). The frequency of accelerating modules is thereby 1 GHz, so that all bunches are accelerated equally. The RF deflector at the injection point of a delay loop has a frequency of 0.5 GHz, so that only bunches of every second train are lead into the delay loop. The length of the delay loop is set to 240 ns, so that the delayed train comes out of the loop simultaneously with the next train passing by the kicker. As a result, both trains leave the kicker together, their bunches being phase-shifted by 180°. Hence, trains of 240 ns length with 240 ns gaps between the trains are created, with the bunch frequency of 1 GHz within the train. A similar principle is used in the first and second combiner ring with phase shift of 120° and 90° respectively.

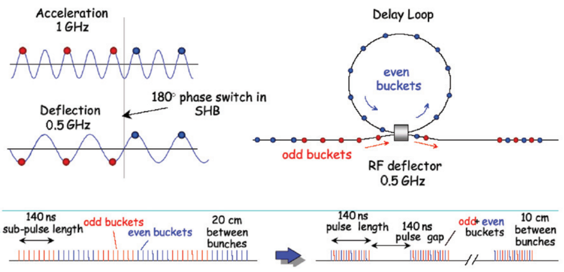

Figure 1: CLIC train combination principle.

BUNCH CHARGE AND PHASE ERRORS IN THE DRIVE BEAM

The bunch phase is influenced along the beamline by the errors in other parameters, such as bunch charge, bunch energy and drive beam gradient and phase. The calculation of the impact of these parameters on the phase error has been performed with help of the developed simulation tool in four steps, corresponding to the four different parts of the drive beam (Fig. 2):

1. Drive beam accelerator
2. Bunch compressor chicane
3. Drive beam combination scheme and
4. Power Extraction and Transfer Structures (PETS) and main linac accelerating structures.

The methods used in these four steps will be described in the following sections, thereafter the final result for the impact on the main beam phase error will be presented.

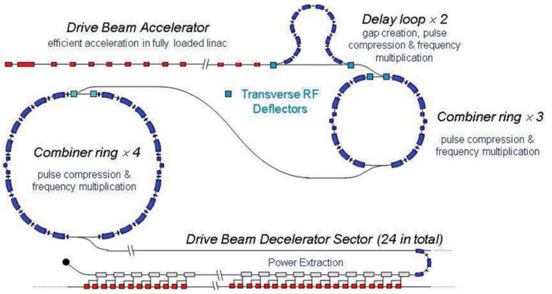

Figure 2: CLIC drive beam layout.

Drive Beam Accelerator

In the drive beam accelerator the RF phase error and RF gradient error lead to beam energy error that causes the phase error in the chicane. Additionally, bunch charge errors cause beam loading error in the accelerator, hence leading to a phase shift in the chicane (see next section). In order to determine the energy error, the RF potential and the wake potential has to be calculated. This calculation was performed by R. Wegner in a frequency domain, including the higher order resonances of the structure, and the result was then transformed into the time domain.

Bunch Compressor Chicane

The bunch compressor is a chicane designed to reduce the drive beam bunch length from 3 mm to 1 mm. It is to be positioned in the in the drive beam accelerator at the energy of 300 MeV. A. Aksoy analyzed four different designs for the chicane and came to the conclusion that the design with R_{56} =-0.1 m allows largest tolerances [3], hence this design was used for the current analysis.

In this chicane bunch phase, length and energy are influenced by the bunch charge. The results for impact of drive beam accelerator errors (RF phase error and RF gradient error) in the chicane from [3] were also considered. There are two additional pairs of compensating compressor and decompressor chicanes on either side of the combination scheme and of the final turn-around, but their impact is irrelevant for the present analysis.

Drive Beam Combination Scheme

The drive beam combination scheme has an important impact on the error propagation. When the errors from different trains come together in one combined train, the sequence of the bunches is changed. For the jitter at the frequencies resonant with the train length, the errors of the neighboring bunches have similar values, and hence their jitter frequency doesn't change much. But in case of non-resonant jitter the errors vary strongly between the bunches, and hence large portion of the error is shifted to the bunch-to-bunch frequency of 12 GHz. At this frequency though the impact of errors on the main beam is negligible, since the RF filling time of the main beam accelerator is in the order of ∼60 ns. Hence, the jitter which is not in resonance with train length is effectively filtered out by the combination scheme (as it can be seen on Fig. 3).

Power Extraction and Transfer Structures (PETS) and Main Linac

In order to analyze the impact of the drive beam errors on the main beam and hence on CLIC luminosity, the convolution of the drive beam errors with the RF filling function of the main beam accelerating structures must be calculated. For that the results of simulation by O. Kononenko for unloaded voltage and wake potential have been used [4]. This simulation was performed in the frequency domain for the first resonant peak in the interval 11.7 GHz - 12.3 GHz. The analysis shows that the convolution acts as a high-frequency filter (see next section).

PHASE ERROR AND ITS CORRECTION

The phase error generated by the errors of the bunch charge and of the accelerator RF amplitude is presented in Fig. 3. The diagram displays the squared mean root phase error of the RF wave extracted from the drive beam relatively to the nominal phase of the main beam bunches. Hence, this error is transmitted to the main beam.

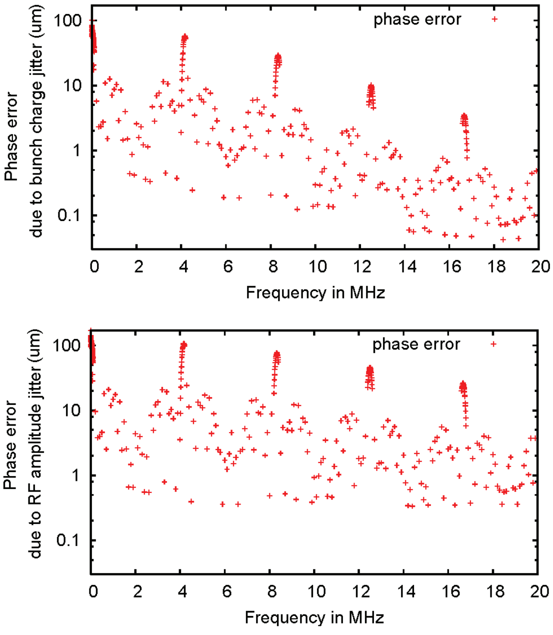

Figure 3: Phase error generated by 0.1% bunch charge (top) and 0.2% drive beam RF amplitude (bottom) errors.

As the diagrams shows, only a fraction of the phase error is left after the combination scheme. The errors between the resonant peaks at n×4.17 MHz are shifted to much higher frequencies and then filtered out by the convolution with the main beam accelerating structure RF filling function. Additionally, the peaks are suppressed because the drive beam accelerator RF fill time was designed to be 240ns long in order to achieve a filtering effect.

Phase Correction with Feedforward System

In order to correct the errors which are left after the filtering, a chicane composed of a phase monitor, an amplifier and electromagnetic kickers can be used [5]. This chicane can act as a feedforward system at the final turnaround of the drive beam.

The bandwidth of a feedforward system is a crucial parameter, as it is demonstrated in Fig. 4. While being similarly efficient at lower frequencies, a faster feedforward system filters out high frequency components much more efficiently.

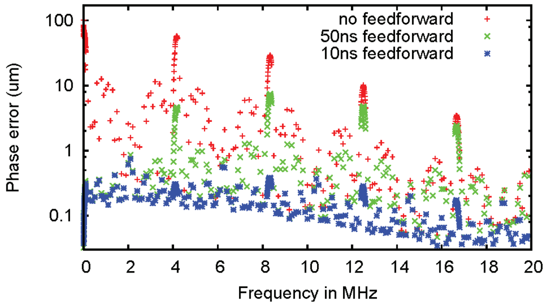

Figure 4: Phase error generated by bunch charge jitter without feedforward (red), with feedforward of 50 ns bandwidth (green) and 10 ns bandwidth (blue).

In Fig. 4 white noise has been assumed, but modifying the type of jitter and integrating over the frequency (from 1 kHz to 20 MHz, since the errors decrease with frequency) leads to the distributions shown in Fig. 5. The first entry on the x-axis is the error before recombination, which has been normalized to one for all noises. The second entry shows the effect of the filtering by the recombination scheme and convolution with main beam RF filling (without feedforward). As one can see, the higher frequencies are filtered much stronger. The following entries represent feedforward systems with different bandwidths from 240ns to 2 ns. The diagram shows that noise with lower frequency sets lower requirements on feedforward bandwidth, since the low frequency components can be corrected well also by a slower feedforward system. The two presented errors (in bunch charge and RF amplitude) as well as errors in RF phase and incoming bunch phase show similar behaviour towards filtering and feedforward. At the moment the design with bandwidth of 20 ns is under consideration for CLIC feedforward system.

CONCLUSIONS AND OUTLOOK

The program tool developed for this study allows to analyze the cumulative effect of errors in the first order approximation and hence to predict the total luminosity loss. It is based on realistic and detailed modeling of drive beam and main beam accelerating structures. It includes the calculation of the interdependencies of different parameters while considering the multi-bunch effects. Hence, with help of the program a precise analysis of the error profile along the CLIC main linac can be performed, which enables the calculation of the local tolerances, additionally to the calculation of the global tolerances for the complete CLIC machine. The analysis of the error frequency spectrum shows that the phase error, compared with constant parameter offset [6], is reduced by factor 10 due to filtering and another factor 10 due to usage of feedforward system, as stated in the introduction. This means that the new tolerances will be dictated by the constraints from the second order effects, such as scale errors or feedforward resolution and capture range. These effects will be studied with help of the developed program tool in the future.

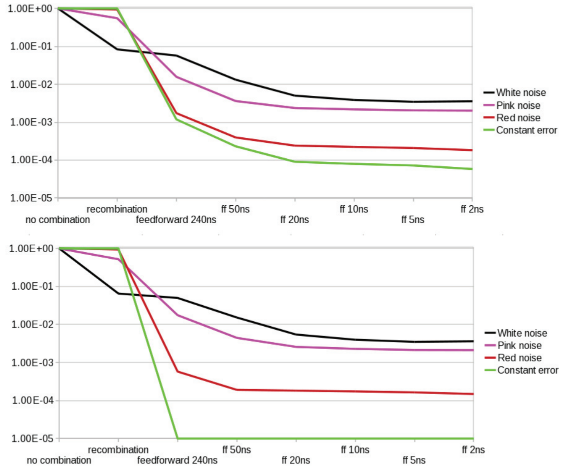

Figure 5: Normalized phase error generated by bunch charge (top) and drive beam RF phase (bottom) errors for different types of noise

The program will be adopted for simulations of the CLIC Test Facility (CTF3) errors, which will be compared with CTF3 measurements of the bunch charge and phase. It can also be used for further main linac studies.

It is planned to install a first prototype of a feedforward system at CTF3 with (improved) phase monitors, pulser and electromagnetic kicker to correct static phase imperfections as well as the average phase errors of the trains.

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