CLIC RECOMBINATION SCHEME FOR THE LOW ENERGY OPERATION MODE

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Abstract

The CLIC recombination scheme is a concept of multiplication of the drive beam frequency in order to generate a 12 GHz RF wave for the main beam acceleration. CLIC is designed to be operated at nominal energy and in low energy modes. The low energy operation modes require the train length to be increased by different factors in order to maintain the same level of luminosity. Also the number of initial trains that are merged to form each final train is changed. The combination scheme must be able to accommodate and recombine both long and short trains for nominal and low energy CLIC operation modes. The recombination hence becomes a non-trivial process and makes the correction of the errors in the drive beam more challenging. The present paper describes in detail the recombination process and its consequences.

INTRODUCTION

The Compact Linear Collider is a potential future linear e^+e^- collider, which is designed to provide acceleration with a gradient of ~100 MV/m. CLIC is supposed to be operated at 12 GHz frequency with 244 ns long RFpulses at nominal energy of 3 TeV [1]. Such pulses cannot be produced by any conventional RF source, but can be extracted from a high-current low energy beam called the drive beam. Drive beam can be accelerated by conventional klystrons at the frequency of 0.5 GHz, later drive beam buckets can be recombined in the so called CLIC drive beam recombination scheme. The buckets of the subsequent trains are repositioned longitudinally between each other, hence increasing the bunch frequency of the beam (see Fig. 1).

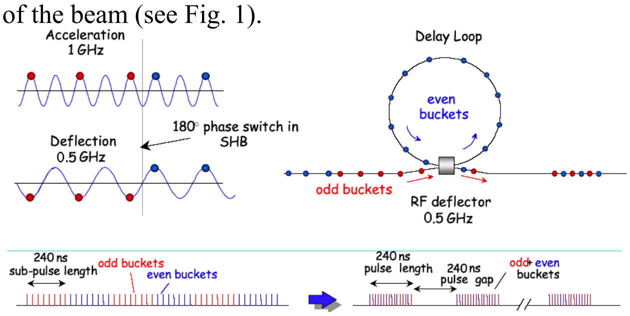

Figure 1: CLIC drive beam combination principle.

The frequency is increased by factor two in a delay line and by factors three and four in the two combiner rings, hence giving a drive beam at the final frequency of 12 GHz.

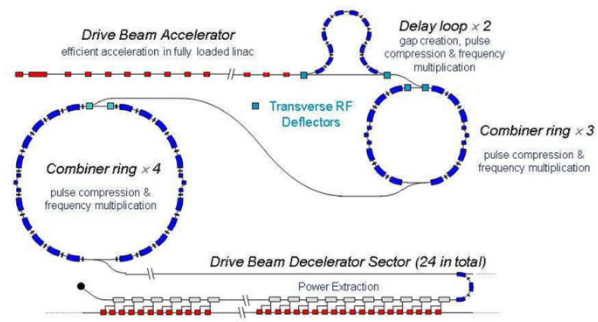

Figure 2: CLIC drive beam accelerator complex and recombination scheme.

DIFFERENT ENERGY MODES

Operating at lower energies is necessary to study the properties of the particles that are expected, or hoped to be discovered, at CLIC. Hence CLIC must allow the possibility of energy scans, which can be performed by reduction of the accelerating gradient. CLIC error tolerances require the bunch charge N to be reduced proportionally to the collision energy E, leading to a significant luminosity drop. In order to compensate for it, it is planned to increase the pulse length and the number of bunches per pulse n_b. This pulse length increase can be performed for several stages of energy reduction, which defines the different energy operation modes [2].

The baseline design implies the construction of four different delay lines for different energy modes. The combiner rings, in contrast, will be designed in order to be able to accommodate all possible pulse lengths in the same structure. The length of the combiner rings is 292.8m for CR1 and 439.2m for CR2.

NOMINAL 3 TeV OPERATION MODE

At the nominal operation mode CLIC drive beam pulses with both even and odd buckets are 244 ns long. After the recombination of the buckets in the delay line, the beam consists of 244 ns long 1 GHz pulses and 244 ns long gaps (as shown in Fig. 1). CR1 will be filled with two pulses simultaneously, separated by two gaps (see Fig. 3). When next two pulses arrive, they will be combined with the ones circulating in the ring, up to the combination factor three. Afterwards, the pulses will be extracted from the combiner ring.

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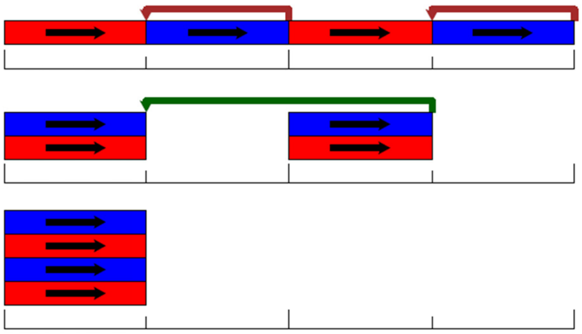

Figure 3: The switching pattern of the nominal 3 TeV mode – 122 even and 122 odd buckets [3].

The above scenario describes the steady state mode. However, the extraction must happen in regular intervals of 6×244 ns for the proper operation of the second combiner ring CR2. This means that the second pulse injected into CR1 must be extracted before it is combined.

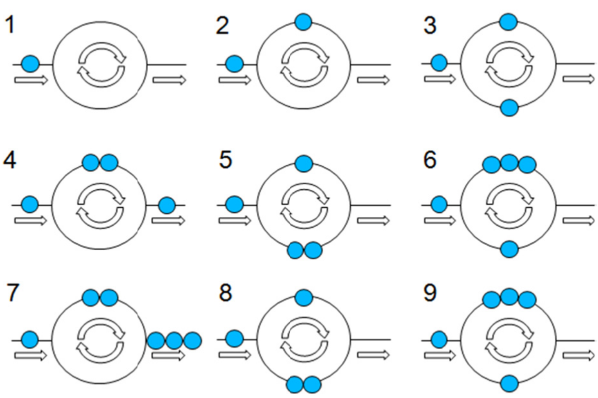

Figure 4: Scheme of first several circulations in CR1. Pulses arrive from the left, circulate clockwise in the ring and leave to the right. Each point represents pulse buckets filled with bunches, hence a doublet or a triplet of points represents the combined pulses with combination factor two or three respectively.

In CR2 pulses of 3 GHz frequency and 244 ns length, separated by 5×244 ns long gaps, circulate four times, being recombined with the following pulses at the end of each cycle (Fig. 5).

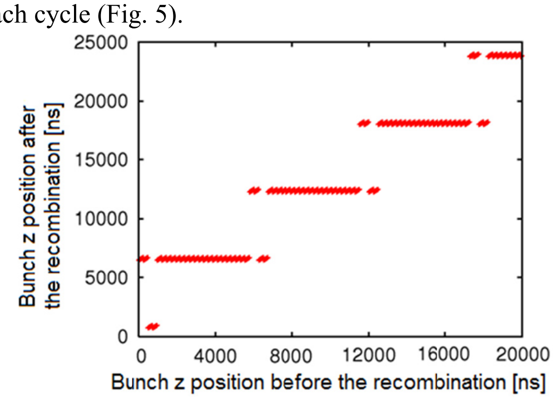

Figure 5: Complete recombination by DL, CR1 and CR2. The factor two recombined pulse is the one ejected without recombination from CR1, the following factor 24 recombined pulses are used for main beam acceleration.

LOWER ENERGY MODES

2.25 TeV Mode

The 2.25 TeV mode requires the pulse length of 4/3·244 ns. Hence, it is planned to produce 163 even buckets followed by 81 odd buckets, then 82 even buckets followed 162 odd buckets and so on (see Fig. 6).

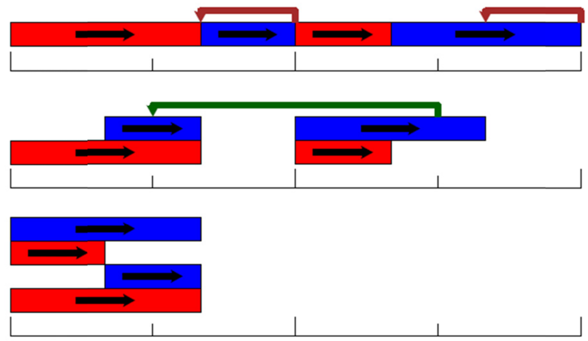

Figure 6: The switching pattern of the 2.25 TeV mode – even and odd pulses come alternating in groups [3].

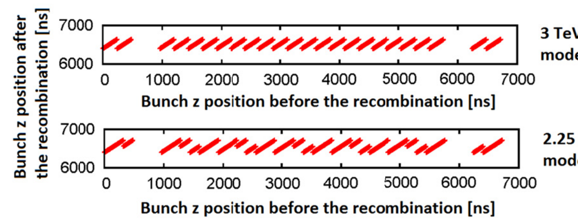

Figure 7: Bunch positioning for the nominal 3 TeV mode (top) and for the 2.25 TeV mode (bottom).

Other Modes

For 2 TeV mode the pulse length must be 3/2×244 ns. The switching pattern functions similarly to the 2.25 TeV mode and implies the alternation between 122 even and 122 odd buckets, then 183 even and 61 odd and afterwards 62 even and 182 odd.

The 1.5 TeV mode has the pulse length of 2×244 ns, so the first combiner ring accommodates only one of the pulses instead of two and the second combiner ring two instead of four [3]. The recombination factors provided by combiner rings stay the same.

The switching pattern for 1.125 TeV mode is analogue to the 2.25 TeV mode.

CONSEQUENCES FOR ERROR PROPAGATION AND CORRECTION

Main Beam Gradient Error

The delay line and the combiner rings have the same deflector frequency at nominal and low energy modes. Hence, they create drive beam with 12 GHz bucket frequency with some of the buckets not being filled with bunches instead of creating a pulse with equidistantly distributed bunches. E.g. the bucket frequency for 2.25 TeV mode is not 9 GHz, but 12 GHz with 1/4 of the buckets being empty.

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Because of that, the resulting main beam RF wave amplitude will not be stable. Preliminary calculations estimate the resulting main beam energy error being in the order of several per mille, which is above the tolerance limit. Hence a further investigation of the errors is necessary.

Main Beam Accelerator RF Phase Error

The drive beam provides the RF power for the main beam acceleration, hence the tolerances on the drive beam parameters are very strict, e.g. the tolerance for the phase error being 0.25° at 12 GHz [4].

Part of the phase error is reduced due to filtering by the recombination scheme, which functions in the following way: when trains get recombined, bunches from different trains are positioned next to each other. Hence, a large proportion of low frequency noise (up to several MHz) is shifted to the higher frequencies, which are later filtered in the main beam RF structures, since the structure has a filling time in the order of 60 ns.

Important exceptions to this filtering are the jitter frequencies, at which the wave length of the jitter corresponds to the train length and so the errors do not cancel out. The example of such filtering is shown in Fig. 8: the noise with originally equal amplitude at frequencies from 10 kHz to 20 MHz is significantly filtered out, in particular at higher frequencies, with the exception of the peaks at n×4.1 MHz, which correspond to 244 ns pulse length.

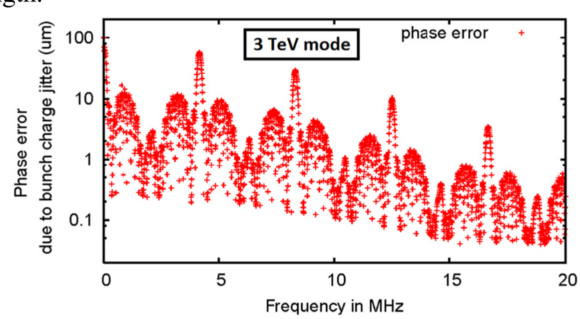

Figure 8: Main beam RF phase error caused by 0.1% drive beam bunch charge error for 3 TeV mode.

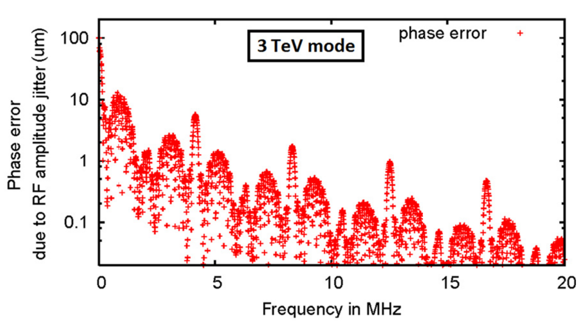

Figure 9: Main beam RF phase error caused by 0.05% drive beam RF amplitude error for 3 TeV mode.

In order to suppress the resonant peaks for the nominal energy case, the length of the drive beam accelerating structure has been set to 244 ns. Hence for the phase error caused by the errors of the drive beam accelerator RF the resonant peaks at 4.1 MHz, or its multiple, are suppressed (compare Fig. 9 with Fig. 8).

This filtering can be set up only for one frequency and its multiples. For different lower energy modes the train lengths are different, and hence all resonant peaks cannot be filtered out by fitting the drive beam accelerator structure length to them. Fig. 10 demonstrates this using the example of the 2.25 TeV mode – in this mode the 488 ns long pulses are divided into ~325 ns and ~163 ns parts which are recombined. Hence the resonant modes are at 2.0 MHz, 3.1 MHz and 6.1 MHz.

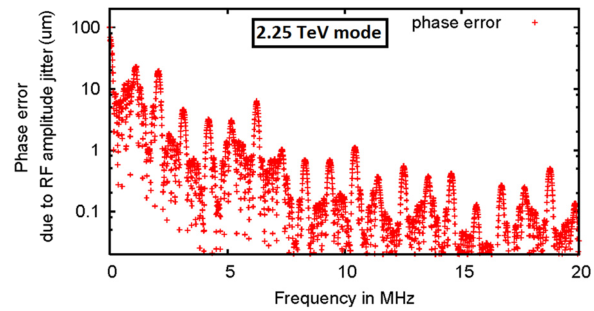

Figure 10: Main beam RF phase error caused by 0.05% drive beam RF amplitude error for 2.25 TeV mode.

The peaks at n×4.1 MHz are filtered out, but the rest of the peaks remains unfiltered. The total RMS error is 5.58° at 12 GHz compared with 4.96° at 12 GHz for the 3 TeV case. This difference is not large, however the feed-forward system functions much less effectively, in particular because the large peaks at 2.0 and 6.1 MHz are not suppressed. E.g. for 20 MHz feed-forward bandwidth the total RMS error drops only to 1.05° at 12 GHz compared with 0.11° for the 3 TeV case.

SUMMARY AND OUTLOOK

Operation of CLIC at low energy modes requires the use of different drive beam recombination patterns [3].

The recombination patterns lead to gradient error in the main beam linac and the amplitude of these errors must be investigated.

The drive beam accelerating structure has been optimized to cancel out resonant errors for the nominal energy mode; however it cannot be adapted to filter out the resonant errors of all lower energy modes. Consequently, the phase error is higher for these modes and the feed-forward system cannot reduce it sufficiently. Hence, additional filtering or correction methods must be considered.

REFERENCES

[1] F. Tecker at al., CLIC parameter table, http://clic-meeting.web.cern.ch/clic-meeting/clictable2010.html
[2] D. Schulte et al. “CLIC Energy Scans” for IPAC’10, Kyoto, Japan, WEPE022
[3] D. Schulte et al., CLIC Conceptual Design Report, chapter 8:“CLIC Operation at Low Energies”
[4] D. Schulte et al. for LINAC2010, MOP024