DESIGN OF THE CLIC DRIVE BEAM RECOMBINATION COMPLEX

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Abstract

The CLIC Drive Beam Recombination Complex (DBRC) is designed to compress beam pulses from a current of 4 A to 100 A before using them to produce RF power in the deceleration lines. The beam is transported isochronously through a complex system consisting of a delay loop, two combiner rings and final turn around. The system is designed to preserve transverse and longitudinal emittances. During the optics design, chromaticity and non-linear dispersion were identified as the main single particle dynamics causes for transverse emittance growth. Different sextupole families are used to compensate these chromatic effects while keeping isochronicity. The bunch length is also adjusted to minimize coherent synchrotron radiation effects on bunch length, energy spread and transverse emittance. Finally, the injection scheme of the combiner rings was improved by making the time-variable bump created with help of the RF deflectors truly achromatic.

INTRODUCTION

The Compact LInear Collider (CLIC) will feature a two beam acceleration scheme that provides accelerating gradients of 100 MV/m. A high intensity beam (or drive beam) is decelerated in the Power Extraction Structures (PETS) where the extracted power is then transferred to the accelerating structures in the main linac. The required drive beam intensity (100 A) and frequency (12 GHz) is obtained by means of the CLIC Drive Beam Recombination Complex (DBRC). The complex multiplies the intensity and the frequency of the incoming beam (4 A and 0.5 GHz, respectively) by a factor 24 through a delay loop ($\times 2$), a first combiner ring ($\times 3$) and a second combiner ring ($\times 4$). The design of BDRC lattice is based on three bend cells, each being achromatic and isochronous.

EMITTANCE PRESERVATION IN THE DBRC

In order to meet the CLIC requirements [1], the total beam transverse emittance growth through the DBRC should be kept below 30%. The drive beam arrives at the recombination complex with a natural high total energy spread of $\delta p/p$ =1% coming from the full beam loading operation in the linac [2]. This requires a high energy acceptance from the complex to transport the beam within the CLIC specifications. We have studied two cases of momentum distribution: Gaussian one with $\sigma = 0.33\%$ and flat one ranging from -1% to 1%. The former one is an optimistic assumption while the latter one represents the worst case scenario.

The transverse emittance growth is mitigated from a double point of view. First, chromaticity and high order dispersion are compensated along the whole DBRC, and second, the coherent synchrotron radiation (CSR) effects in the delay loop are evaluated.

Chromaticity and Non-linear Dispersion Compensation

The bunch length should be preserved through all the DBRC implying isochronous optics in the whole complex ($R_{56} = 0.0 \pm 0.01$). These optics require relatively strong focusing and hence the non-linearities of the optical functions are very pronounced, reducing the energy acceptance of the system. Calculations were done with PTC [3] which provides reliable modelling of higher order effects.

Figure 1 shows the final horizontal position of particles with the same initial conditions but different energy. Particles above $|\delta p/p| > 0.5\%$ present already too large excursions. The dispersion is kept to relatively low values within

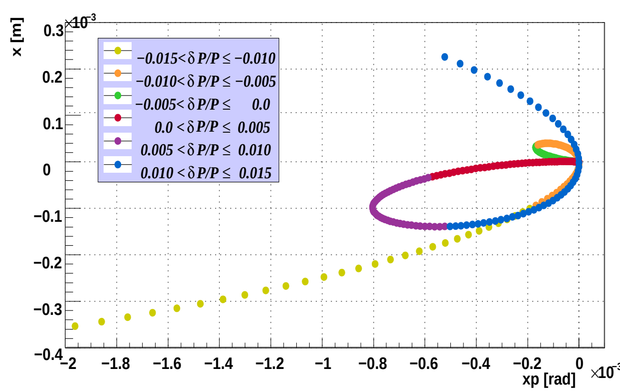

Figure 1: Horizontal position (x) at the end of CR1 for particles with the same initial coordinates but different energy. Particles with $|\delta p/p| > 0.01$ drift away clearly after one turn.

the basic isochronous cell to reduce the energy dependence in the design. Chromaticity, second order isochronicity T_{566} and high-order dispersion (up to 4th) are minimized using sextupoles. For most of the lines it was impossible to find a setting that minimizes those functions all together. In such cases vertical chromaticity is left non zero, which is the driving term for the vertical emittance growth. The transverse emittance growth results in the different DBRC stages are presented in Table 1.

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Table 1: Summary of expected emittance growth in the different stages of the DBRC assuming 100 mm · mrad initial transverse emittances and flat momentum distribution. Values quoted in parentheses correspond to the Gaussian distribution.

	$\Delta\epsilon_x$[%]	$\Delta\epsilon_y$[%]
Delay Loop	20 (5)	20 (7)
Transfer Line 1	< 1 (< 1)	< 1 (< 1)
Combiner Ring 1	15 (4)	10 (5)
Transfer Line 2	2 (1)	< 1 (< 1)
Combiner Ring 2	20 (16)	20 (16)

Coherent Synchrotron Radiation

Particles within a bunch will experience coherently the fields produced by the other particles when the wavelength is similar to the bunch length. This coherent synchrotron radiation process will produce an energy loss in the bunch with the subsequent increase of the energy spread and increase of the transverse emittance. In the DBRC the largest influence of the CSR on the beam dynamics is expected in the delay loop, where the dipole bending radius is smaller.

Simulations with `elegant` [4] neglecting shielding effects show a clear dependence on the bunch length of the horizontal emittance perturbation. Simulations done with a beam having Gaussian distribution on the 6 coordinates (with $\sigma_p = 0.6\%$ and $Q = 8.4 \cdot 10^{-9}$ C) show that for $\sigma_l = 1mm$ the emittance growth is much larger (factor 3.5, as shown in Fig. 2) than with respect to the no CSR case, while for $\sigma_l = 2mm$ is of the order of 50%. Stretching the beam through a magnetic chicane just before the delay loop is therefore necessary. The CSR effects depend strongly not only on the bunch length but also on

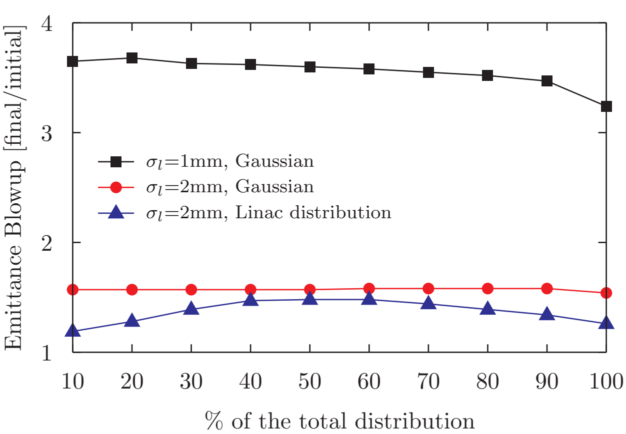

Figure 2: Emittance blowup in the horizontal plane due to CSR for different distributions and bunch lengths. Particles are binned w.r.t. to their horizontal invariant and ratio of the emittances for respective bins is plotted.

the longitudinal phase space distribution form. The beam distribution obtained tracking the beam along the linac and in the stretching chicane [5, 1], has been used as input for elegant and transported through the DL. In this case the horizontal emittance degradation is almost acceptable (20% increase and some distortion in the distribution), and better than the one obtained with the Gaussian longitudinal distribution. Fig. 3 shows the corresponding horizontal

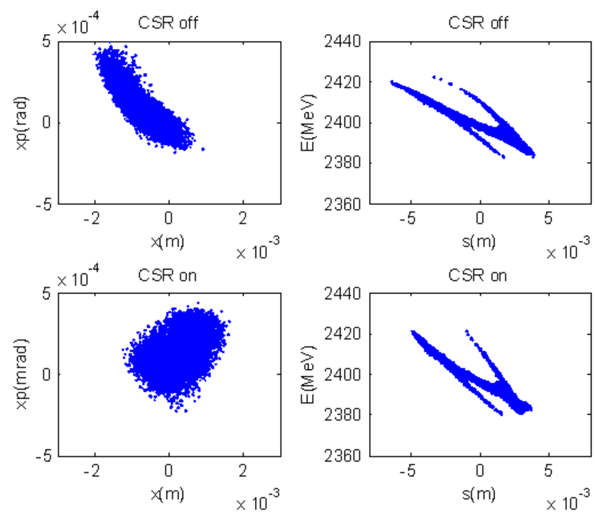

Figure 3: Horizontal and longitudinal phase space distribution after the passage in DL of the beam coming from LINAC, without and with CSR included

and the longitudinal phase spaces after the DL without and with CSR effects. The longitudinal phase space correlation introduced by the chicane will be used after the DBRC to compress the beam before the final Turn Around.

INJECTION WITH RF DEFLECTOR

The beam recombination technique is based on the time varying injection bumps created with the RF deflectors [6]. The lattice of the combiner rings must fulfill several requirements to assure their operability and stability of the recombined beam.

1. The RF bump offset at injection should be 2.5 ± 0.5 cm.
2. RF deflector kick should be as small as possible, preferably below 2.5 mrad.
3. After the bump the dispersion should be at the level of the natural dispersion, i.e. $D_x \pm 0.05$ $D'_x \pm 0.01$.
4. The horizontal phase advance between RF deflectors is $\Delta\mu_x = 180°$ [7].
5. β functions should be kept as small as possible in the RF deflector (current limit $\beta < 10$ m) [7].

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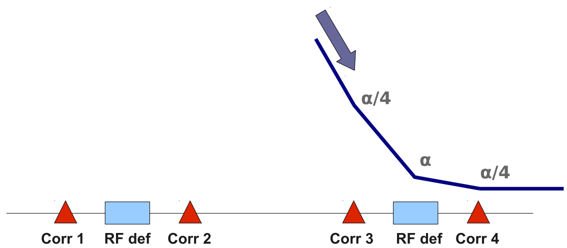
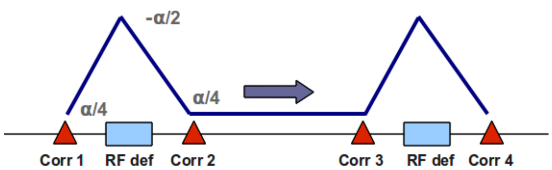
6. (Q_x,Q_y)=(0.6±0.04,0.6±0.04) to minimize emittance growth due to RF deflectors [7].

Additionally, the RF bump is not achromatic by definition. The dispersion correction scheme is different depending on the combination factor. For the first combiner ring, factor ×3, the correction can be done using four additional static orbit correctors around each RF deflector, as shown in Fig. 4. The injected train is put on the ring's closed orbit with the help of both, RF deflector and the correctors (Fig. 4a), while the trains already circulating in the ring follow the closed bump created by the correctors (Fig. 4b). In the combination factor 4 case the static correction scheme cannot be applied as the bump in the 3rd turn is different from the 2nd and 4th. Instead, two families of sextupoles are needed to close the dispersion for all turns (Fig. 5).



(a) Orbit during injection



(b) Orbit during 2nd and 3rd turns

Figure 4: Sketch of the factor 3 recombination process. The incoming train is injected using a septum and corrector (top) while the already circulating trains follow the closed bump produced by the four orbit correctors (middle).

CONCLUSIONS

The DBRC has been designed according to CLIC requirements on isochronicity and transverse emittance preservation. The lattice design targets maximum energy acceptance. The non-linear dispersion was identified as the most important factor reducing it. In the described design sextupoles are used to minimize the non linear behaviour of the dispersion permitting the beam transport with minimized emittance growth.

The chicane before the delay loop stretches the bunches which minimizes the CSR effects on the emittance growth. The total momentum spread might be also reduced by

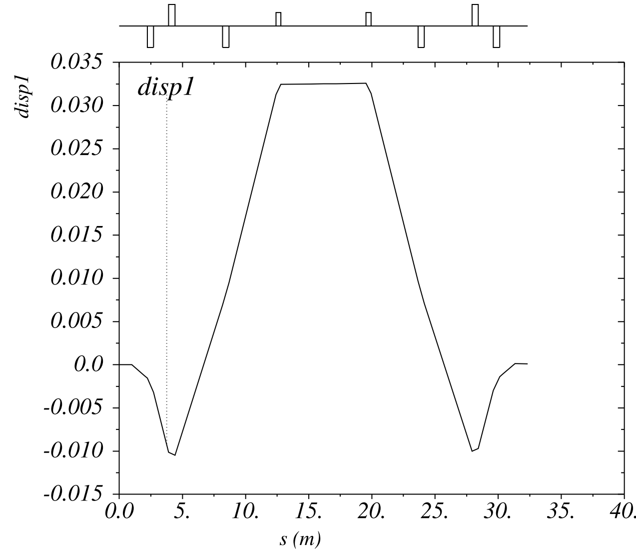


Figure 5: Horizontal dispersion in CR2 in the RF bump is closed using two families of sextupoles.

adding an RF cavity that would remove the correlated energy spread. Similarly, such a cavity shall be installed after DBRC and before the compression chicane, in order to regenerate the energy chirp. Reducing the overall energy spread would tremendously facilitate the beam transport through the Drive Beam Recombination Complex. On the other hand, such RF cavities may introduce additional phase jitter of the drive beam. The influence of such system on the beam stability shall be further studied.

The current layout of the delay loop minimizes its size. It is possible to achieve a better performing lattice by making it larger.

Additional simulations of CSR including shielding effects are ongoing. Finally, different injection schemes using RF deflectors have been designed obtaining truly achromatic bumps for the different combination factor schemes.

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