A BUNCH COMPRESSOR FOR THE CLIC MAIN BEAM*

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Abstract

The last bunch compressor chicane in front of the main linac of the multi TeV linear collider CLIC is foreseen to longitudinally compress the incoming electron bunches from $\sigma_s = 250\ \mu\mathrm{m}$ to $\sigma_s = 30\ \mu\mathrm{m}$. It is specified that the emittance growth in this chicane, which is mainly due to incoherent and coherent synchrotron radiation, should not exceed $30\,\mathrm{nm\,rad}$ in the horizontal plane and $1\,\mathrm{nm\,rad}$ in the vertical plane. To achieve these values the chicane layout and the optics functions have been optimized and the influence of shielding due to the vacuum chamber has been studied. The importance of the CSR micro bunch instability is discussed. Chicane layouts and the corresponding electron beam parameters are presented, which allow to preserve the emittance within the specifications.

INTRODUCTION

In the CLIC TDR [1] it is specified, that at the interaction point the bunch length should not exceed $\sigma_s = 30\ \mu\mathrm{m}$ and that the horizontal and vertical normalized emittances should be less than $\varepsilon_{n,x} = 600\mathrm{nm\,rad}$ and $\varepsilon_{n,y} = 5\mathrm{nm\,rad}$ respectively. Further upstream at the entrance of the second bunch compressor (BC2) these values are: $\sigma_s = 250\ \mu\mathrm{m}$, $\varepsilon_{n,x} = 570\,\mathrm{nm\,rad}$ and $\varepsilon_{n,y} = 4\,\mathrm{nm\,rad}$. In consequence, BC2 has to compress longitudinally the electron bunches by a factor of 8.3 while keeping the horizontal emittance growth below 5% and preserving the vertical emittance.

Emittance growth in bunch compressors is generated by the synchrotron radiation emitted by the electrons when passing the bending magnets. It can be incoherent synchrotron radiation (ISR) and coherent synchrotron radiation (CSR) and almost only effects the phase space distribution in the bending plane. Hence, the emittance growth in the vertical plane, i.e. perpendicular to the beneding plane, can be assumed to be negligible.

In Ref. [2] it was shown how ISR and CSR emittance growth in BC2 depend on the dipole length. A dipole length of $L_B = 2\ \mathrm{m}$ and a total chicane length of $L_{tot} = 40\ \mathrm{m}$ were chosen. Several C-shaped chicanes (Figure 1a) and S-shaped chicanes (Figure 1b) were compared including asymmetric layouts were the inner dipoles have been moved. The results were, that both types of chicanes can be built in a way that the emittance growth remains lower than the allowed emittance growth. However, the S-chicanes gave better results.

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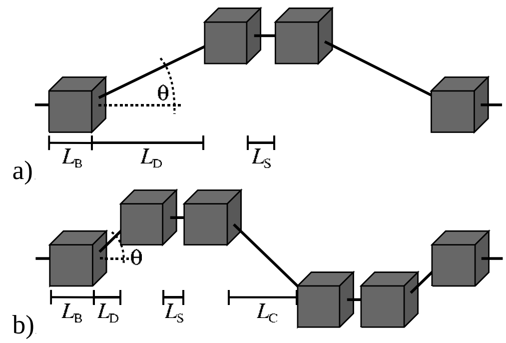

Figure 1: C-chicane (a) and S-chicane (b).

	Symbol	Value	Unit
Total length	L_{tot}	40.0	m
Dipole length	L_B	2.0	m
Dipole pair separation	L_S	1.0	m
Momentum compaction	R_{56}	-0.014	m

Table 1: Parameters common to all bunch compressor chicanes considered for BC2

Since symmetric beta functions were previously used, an optimization of the optics functions and the layout is performed. Afterwards the influence of the conducting walls of the vacuum chamber on beam dynamics is studied and a brief discussion of the CSR microbunch instability in BC2 is given. Parameters common to all chicanes which are compared are given in Table 1. Electron beam parameters are given in Table 2.

OPTIMIZATION OF LAYOUT AND TWISS FUNCTIONS

In Ref. [3] it is shown that CSR favors a waist of the horizontal beta function closer to the last magnet of the chicane. Hence, an optimisation of the initial twiss functions is of

	Symbol	Value	Unit
Electron energy	E_0	9	GeV
Bunch charge	Q_0	0.41	nC
Bunch length	$\sigma_{s,i}$	250	μm
Unc. energy spread	$\frac{\sigma_{E,unc}}{E_0}$	$2 \cdot 10^{-3}$	
Linear s-E correlation	$\frac{1}{E_0}\frac{dE}{ds}$	-70.5	m^{-1}
Normalized emittance	$\varepsilon_{n,x}$	570	nm rad

Table 2: Parameters of the electron bunches in front of the chicane.

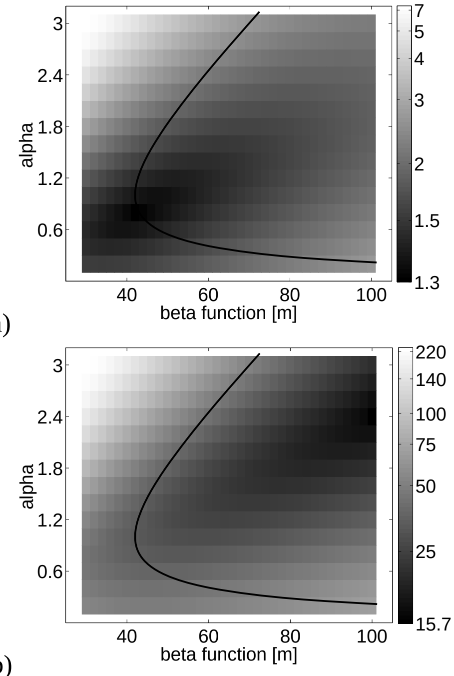

Figure 2: Dependence of ISR (a) and CSR (b) emittance growth on initial beta function and alpha. White means low emittance growth and black means high emittance growth. The black lines mark the initial values giving a symmetric beta function.

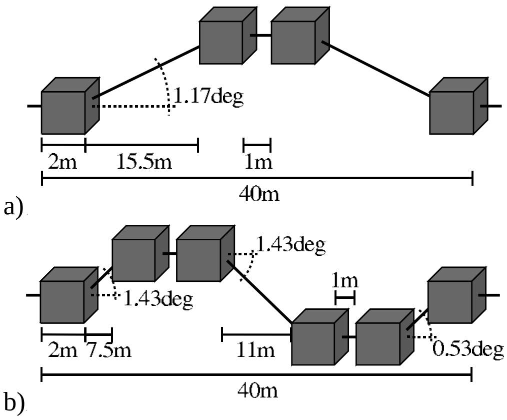

Figure 3: Optimized geometries of the C-chicane (a) and the S-chicane (b).

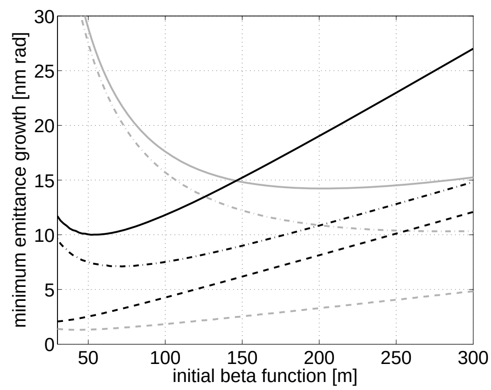

Figure 4: Minimum ISR (dashed), CSR (dash dotted) and ISR+CSR (solid) emittance growth vs. dipole shift for the C-chicane (gray) and the S-chicane (black).

utmost importance. Also the ISR emittance growth can be reduced by optimizing the twiss functions, but the optimum values are not necessarily the same as for the CSR emittance growth. Scans of the initial beta function and the alpha for a symmetric C-chicane are shown in Figure 2. It can be seen that in this case the ISR emittance growth is smallest for inital values of beta function and alpha which give a symmetric beta function along the chicane. The optimum initial beta function is about the smallest one for which this is possible. On the other hand, the CSR emittance growth is smaller for large initial beta functions which give a waist of the beta function close to the end of the chicane. Note that in asymmetric chicanes the optimum values will be different and the ISR emittance growth might not favor symmetric beta functions any more.

The CSR emittance growth was simulated with the code CSRTrack [4]. It makes use of the analytical equations for the longitudinal synchrotron radiation field derived in Ref. [5]. In this paper a Gaussian charge distribution is assumed. The ISR emittance growth is obtained from numerical integrations of the equation:

$$\Delta\varepsilon_{\mathrm{n,x}} = 4 \cdot 10^{-8} E_0^6 I_5 \; .$$

Here I_5 is the fifth synchrotron radiation integral and E_0 is the electron energy [6].

For the C-chicanes a three-dimensional scan of dipole position, beta function and alpha, i.e. a scan covering the full parameter space, was performed. Since in an S-chicane there are two additional degrees of freedom for the dipole position, the parameter space was only partly scanned. The layouts of the optimum C-chicane and the optimum S-chicane found in these scans are shown in Figure 3. The emittance growth in these chicanes vs. the inital beta function is plotted in Figure 4. For each point the minimum value from the scan of the alpha has be taken.

The best initial Twiss parameters which were found are $\beta_{\mathrm{x}} = 200\ \mathrm{m}$, $\alpha_{\mathrm{x}} = 4.8$, $\Delta\varepsilon_{\mathrm{n,x}} = 14\ \mathrm{nm\,rad}$ for the C-chicane and $\beta_{\mathrm{x}} = 52\ \mathrm{m}$, $\alpha_{\mathrm{x}} = 1.6$, $\Delta\varepsilon_{\mathrm{n,x}} = 10\ \mathrm{nm\,rad}$ for the S-chicane.

SHIELDING EFFECT OF THE VACUUM CHAMBER

In the previous section all simulations were performed without taking into account the conducting walls of the vacuum chamber. Its most important effects on beam dynamics are due to the shielding effect [7] and the resistive wall wakes [8]. The dependence of the CSR emittance growth in the optimized C-chicane and S-chicane on the chamber height is shown in Figure 5. In order to achieve a notice-

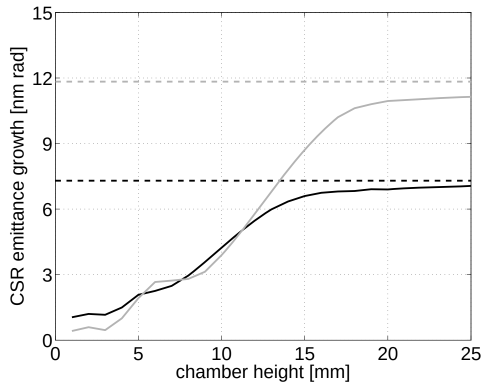

Figure 5: CSR emittance growth vs. chamber height (solid) in the C-chicane (solid gray) and the S-chicane (solid black). For comparison the free space CSR emittance growth is also plotted (dashed)

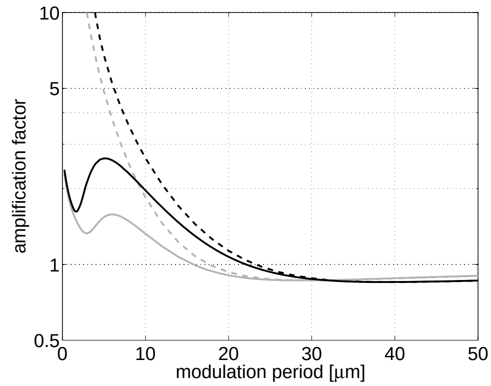

Figure 6: Gain of an initial density modulation due to the CSR microbunch instability in the C-chicane (gray) and the S-chicane (black) with $\sigma_{\mathrm{E,unc}} = 0\,\mathrm{eV}$ and $\varepsilon_{\mathrm{n,x}} = 0\,\mathrm{nm\,rad}$ (dashed) and $\varepsilon_{\mathrm{n,x}} = 570\,\mathrm{nm\,rad}$ (solid).

able reduction of the CSR emittance growth, the chamber height has to be smaller than $20\,\mathrm{mm}$. In these flat chambers resistive wall wakes might lead to a small emittance growth. This remains to be studied. Nevertheless, as we have seen we do not rely on shielding to reduce the CSR emittance growth to acceptable levels and large chamber cross sections can be used.

CSR MICROBUNCH INSTABILITY

As was shown analytically in Ref. [9] and Ref. [10] the coherent synchrotron radiation emitted in a bunch compressor chicane can lead to a strong amplification of density and energy fluctuations in the longitudinal phase space distribution. This effect is called CSR microbunch instability. It is an additional source of emittance growth. Uncorrelated energy spread and transverse emittance can reduce this effect.

In case of BC2 performing numerical integrations of the equations given in Ref. [10] leads to the graphs shown in Figure 6. Already a very small but finite emittance effectively reduces the amplification. The expected uncorrelated energy spread suppresses initial modulations completely.

CONCLUSION

A systematic study of the influence of Twiss functions and geometric layout on the emittance growth for the second bunch compressor chicane in the CLIC main beam line was performed. Two possible layouts for this bunch compressor were found: a symmetric C-chicane and an asymmetric S-chicane. The emittance growth in the chicanes is $\Delta\varepsilon_{\mathrm{n,x}} = 14\,\mathrm{nm\,rad}$ and $\Delta\varepsilon_{\mathrm{n,x}} = 10\,\mathrm{nm\,rad}$ respectively. Hence, it is lower than the specified maximum value of $\Delta\varepsilon_{\mathrm{n,x,max}} = 30\,\mathrm{nm\,rad}$. Due to the optimisation of the twiss function the two chicanes are now closer to each other than in our previous paper [2], but the S-chicane is still giving the better results. Both chicanes do not rely on shielding due to the vacuum chamber. For effective shielding the height of the vacuum chamber would have to be smaller than $20\,\mathrm{mm}$. The CSR microbunch instability is neither in the C-chicane nor in the S-chicane an issue since the uncorrelated energy spread is large enough.

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