DESIGN STUDY OF THE CLIC BOOSTER LINAC WITH FODO LATTICE*

Dou Wang[1#], Daniel Schulte[2], Jie Gao[1], Frank Stulle[2]
[1]IHEP, Beijing, China, [2]CERN, Geneva, Switzerland

Abstract

A new design of the 6.6GeV Booster linac for CLIC which is based on the FODO lattice is presented in this note. Particle tracking studies using PLACET [1] are performed in order to estimate the single-bunch and multi-bunch emittance growth. First, the studies of optics are introduced. Then, the sing-bunch effects and multi-bunch effects are studied in the later two parts of this note.

INTRODUCTION

The CLIC Booster Linac has to accelerate both electron and positron main beams from 2.42 to 9 GeV downstream of the damping rings. In order to increase the beam energy from 2.42 to 9 GeV, we propose to use 73 accelerating structures operating at 4GHz, with a loaded gradient of 30MV/m and a length of 3m each. We chose a FODO lattice in this note to keep the beams focused (A first design of the Booster Linac was described in [2,3]. In that study, the proposed optics for the Booster Linac were based on a Triplet lattice.). Simulations using the code PLACET [1] are performed in order to estimate the single-bunch and multi-bunch emittance growth.

The main beam properties at the entrance of the Booster Linac are given in Table 1.

Table 1: Beam Parameters at the Entrance of the Booster Linac

Beam energy (GeV)	2.42
Normalized emittance (nm.rad)	500
Normalized vertical emittance (nm.rad)	5
Enery spread (MeV)	29
Bunch length (μm)	175
Bunch spacing (cm)	15
Number of electrons per bunch	3.72×109
Number of bunches per train	312

A succession of FODO cells is used all along the linac, each containing the same number of accelerating structures between two adjacent quadrupoles. Each quadrupole has a length of 30cm and the spacing between quadrupole and accelerating structures (as well as between two consecutive accelerating structures) is 30 cm, see Figure 1. There are two main sources of transverse emittance dilution in linear accelerators. One are the transverse wakefields excited in the accelerating sections and the other are the dispersive errors caused by quadrupoles. The focusing force from quadrupoles can help to suppress the wakefield effects. But too strong focusing forces (more quadrupoles or stronger quadrupole strength) will make the dispersion effects become dominant and emittance is enlarged. Hence, we try to find a balance between these two contributions to the transverse emittance growth.

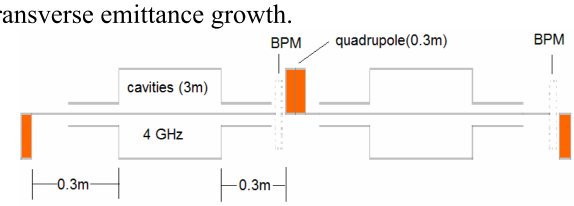

Figure 1: Layout of one FODO cell.

SINGLE-BUNCH EFFECTS

To study the single bunch dynamics, we use a short-range analytic approximation for the point-like charge wake function. Considering our accelerating structures's geometry is scaled from NLC (a=11mm, R=32mm, g=21mm, L=25mm, see Figure 2), we can use the formulae for NLC directly,

$$\begin{cases} W_L(s) = \dfrac{Z_0 c}{\pi a^2} H(s) e^{-\sqrt{s/s_0}} \\ W_\perp(s) = \dfrac{4 Z_0 c s_0}{\pi a^4} H(s)[1-(1+\sqrt{\dfrac{s}{s_0}})e^{-\sqrt{s/s_0}}] \end{cases}$$

$$s_0 = \frac{g}{8}\left(\frac{a}{\alpha(\frac{g}{L})L}\right)^2, \alpha(x) = 1 - 0.4648\sqrt{x} - (1-0.9296)x$$

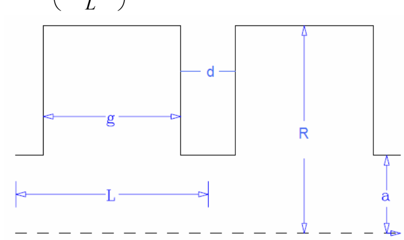

Figure 2: Geometry needed for PLACET simulations.

First, we study the single-bunch emittance growth caused by the transverse wakefields of randomly misaligned cavities using FODO lattice and Triplet lattice seperately. We changed the quadrupole strength to scan the phase advance per cell from 0°to 180° (For Triplet lattice, we adjusted the strengthes of middle quadrupoles and outer quadrupoles to keep the same horizontal and vertical phase advance per cell.) and added accelerating structures gradually in each accelerating section. The average emittance dilution for a single bunch is calculated from 100 different random seeds of cavity misalignments with δyc=100μm (rms), see Figure 3 and Figure 5. Figure

*Work supported by the Commission of the European Communities under the 6th Framework Programme "Structuring the European Research Area" contract number RIDS-011899, and the National Foundation of Natural Sciences contract 10525525 and 10775154.
#wangdou@ihep.ac.cn

4 and Figure 6 show the minimum emittance each structure can get according to Figure 3 and Figure 5, respectively. Figure 7 shows the β functions of FODO1 along the linac.

Compare Figure 4 with Figure 6, we can see that, roughly, T3 is equal to FODO1, T6 is equal to FODO2, T9 is equal to FODO3 and so on. The minimum emittance growth decreases with decreasing number of quadrupoles first and then increases again after T3. The first part of the curve in Figure 6 indicates too strong focusing (dispersive effects dominate) and the later part indicates weak focusing (wakefield effects dominate). Also, we can see there is no significant advantage for Triplet lattice, so we choose FODO lattice in the note for its simplity.

Among the 10 different FODO structures, FODO7, FODO8, FODO9 and FODO12 result too high emittance growth because of the weak focusing. The other 6 are ok with respect to emittance growth. If we consider the cost issue, we would tend to choose a structure with low number of quadrupoles.

Since the misalignment of quadrupoles and BPMs in the linac can cause emittance growth through wakefields and dispersion effects as well, we also have to consider these two kinds of misalignment. We studied the two effects separately (assuming both the two alignment errors are 100μm and BPM resolution is 10μm). The results after one-to-one correction are shown in Figure 8 and Figure 9 for quadrupole error and BPM error, respectively (random seeds are still 100).

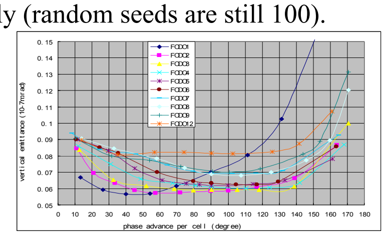

Figure 3: vertical emittance growth versus quadrupole strength and different number of accelerating structures per cell (δyc=100μm).

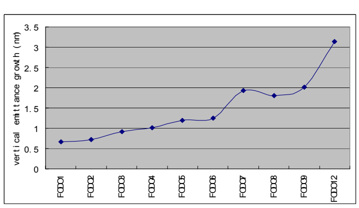

Figure 4: minimum emittance each structure can get according to Figure 3.

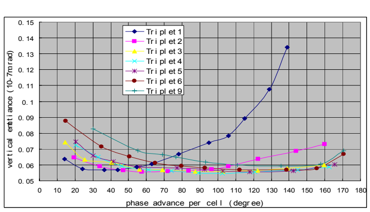

Figure 5: vertical emittance growth versus quadrupole strength and different number of accelerating structures per cell (δyc=100μm).

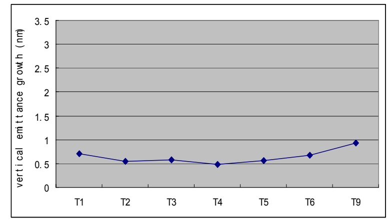

Figure 6: minimum emittance each structure can get according to Figure 5.

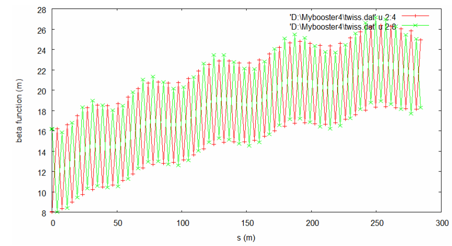

Figure 7: β functions of FODO1 versus the longitudinal position (green: βy; red: βx).

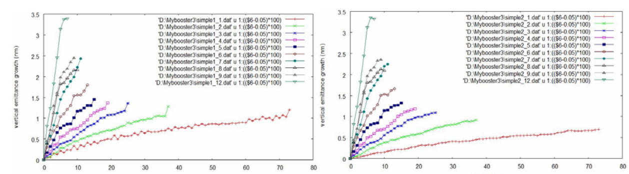

Figure 8: vertical emittance growth including cavity and quadrupole misalignment after one-to-one correction (left: initial energy spread included, right: without initial energy spread).

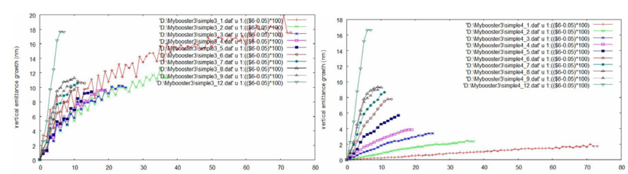

Figure 9: vertical emittance growth including cavity and BPM misalignment after one-to-one correction (left: initial energy spread included, right: without initial energy spread).

In order to control the vertical emittance, wakefield-free steering is used in this note (all three misalignment errors are 100μm and BPM resolution is 10μm), see Figure 10. The final emittance for each structure after wakefield-free steering is shown in Figure 11.

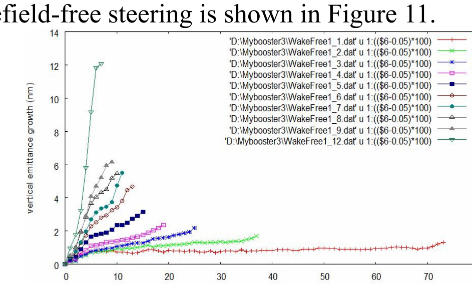

Figure 10: vertical emittance growth after wakefield-free steering including cavity, quadrupole and BPM misalignment (include initial energy spread).

We also tried dispersion-free steering (also see Figure 11). The result of dispersion-free steering seems a little better than wakefield-free steering. We can see that the average emittance growth can be controlled to 1.2 nm for FODO1 after dispersion-free steering.

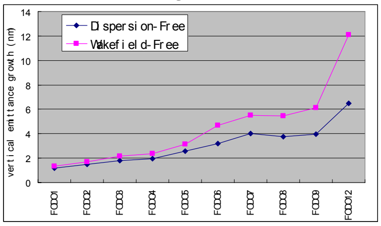

Figure 11: vertical emittance growth after wakefield-free steering and dispersion-free steering.

MULTI-BUNCH EFFECTS

Since long-range wakefields have not yet been calculated numerically, we use J. Gao's analytical formulae[4] to calculate the loss factors (wakefields) and estimate multi-bunch emittance growth. In this note, we just use the fundamental mode and the first dipole mode as an approximation of long-range wakefields.

a) For TM_{010} mode,

The crossing of dispersive curve and the line with light speed can give us the approximate working mode ($\theta_{010}\approx 2\pi/3$) and the fundamental frequency ($f_{\theta 010}$=3.8GHz) which is very close to the design value 4GHz.

The loss factor is 30.6 V/pc/m by calculation. So, the longitudinal wakefield is,

$$W_{L,010}(s) = 2k_{010}\cos(\frac{\omega_{\theta_{010}}}{c}\cdot s)$$

b) For TM_{110} mode,

Combining the dispersive curve and the line with light speed, we can get θ_{110} approximately equal to $5\pi/6$, and the frequency of first dipole mode $f_{\theta 110}$ is 5.03GHz.

The loss factor is 29.06 V/pc/m. So, the transverse wakefield is,

$$W_{T,110}(s) = \frac{2ck_{110}r_0}{\omega_{\theta_{110}}a^2}\cdot\sin(\frac{\omega_{\theta_{110}}}{c}\cdot s)\cdot e^{-\frac{\omega_{\theta_{110}}\cdot s}{2cQ_{\theta_{110}}}}\cdot(\overset{\vee}{r}\cos\phi-\overset{\vee}{\phi}\sin\phi)$$

The amplitude of transverse wakefield which is needed in PLACET is,

$$A_{110} = \frac{2ck_{110}}{\omega_{\theta_{110}}a^2} = 4560V/pc/m^2$$

Some primary simulations show that the first dipole mode alone can lead to a large multi-bunch emittance growth. In order to suppress the multi-bunch emittance growth, we tried cavity detuning method (assuming the linac has no misalignment and the initial beam displacement is 10μm). First, we use two frequencies ($f_0\pm$0.5GHz) with a difference of 1GHz to place the following bunch at the first null of the total wakefield according to

$$A\sin(\omega_1 t) + A\sin(\omega_2 t) = 2A\sin(\frac{\omega_1+\omega_2}{2}\cdot t)\cdot\cos(\frac{\Delta\omega}{2}\cdot t),$$

see Figure 12. Obviously, the emittance is controlled after detuning. Then we use a gauss frequency distribution (assuming the rms frequency spread σ_f is 0.2GHz and the cut of the frequency spread is 3 σ_f) to simulate the random cavity fabrication errors. The result is shown in Figure 13. So the transverse wakefield can be reduced apparently by the natural frequency spread.

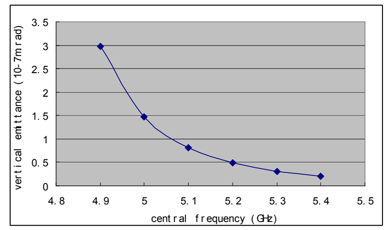

Figure 12: vertical muli-bunch emittance versus central frequency by two-frequency detuning (δy0=10 μ m,nb=312).

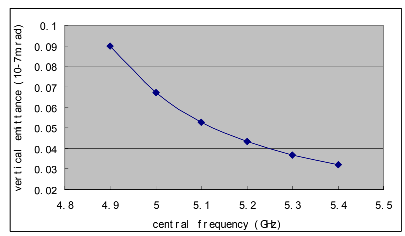

Figure 13: vertical muli-bunch emittance versus central frequency by gauss-frequency detuning (δy0=10 μ m,nb=312).

CONCLUSION

A new design of the CLIC Booster Linac with FODO lattice based on a balance between wakefield effect and dispersive effect is presented in this note. Particle tracking studies using PLACET are performed in order to estimate the single-bunch and multi-bunch emittance growth. The results of PLACET simulations show that single-bunch emittance growth is not a problem for beam performance in the Booster. But multi-bunch emittance growth may be very large without cavity detuning. Anyway, the multi-bunch dynamics should be studied further after the cavity design is finished and the numerical results of wakefield are given.

REFERENCES

[1] http://savannah.cern.ch/project/placet.

[2] A. Ferrari, "Design study of the CLIC Injector and Booster Linacs", CARE/ELAN Document-2007-018.

[3] A. Ferrari, A. Latina and L. Rinolfi, "Design Study of the CLIC Injector and Booster Linacs with the 2007 Beam Parameters", CLIC Note 737.

[4] J. Gao, "Analytical formulae for the loss factors and wakefields of a disk-loaded accelerating structure", LAL/RT 95-01.