THE ACCELERATING STRUCTURE FOR A 500 GEV CLIC

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Abstract

The rf design of an accelerating structure for the 500 GeV CLIC main linac is presented. The design takes into account both aperture and HOM damping requirements coming from beam dynamics as well as the limitations related to rf breakdown and pulsed surface heating. In addition, the constraints related to the compatibility with 3 TeV CLIC have been taken into account. The structure is designed to provide 80 MV/m averaged accelerating gradient at 12 GHz with an rf-to-beam efficiency as high as 39.8 %.

INTRODUCTION

CLIC (Compact Linear Collider) project parameters are summarized in [1]. In order to reach its design luminosity and energy (~10^{35} cm^{-2}sec^{-1} and 3 TeV, respectively) in a power-efficient way and with an affordable site length careful optimization of the CLIC main linac parameters including operating frequency and accelerating gradient has been done as described in [2,3]. Final design of the 3 TeV CLIC main linac accelerating structure operating at 12 GHz and at average accelerating gradient $<E_{acc}>$ of 100 MV/m is described in [4]. On the other hand, a scenario where CLIC is built in stages starting from lower energy is possible. The centre-of-mass collision energy of 500 GeV for the first stage is reasonable and also convenient since it gives direct comparison between CLIC and other linear collider projects: NLC/JLC and ILC.

In this report, modification of the procedure used for 3 TeV CLIC main linac optimization [2,3] is described. The modified procedure is applied to the case of 500 GeV CLIC and the results are presented and discussed.

BEAM DYNAMICS CONSTRAINTS

The beam parameters for CLIC at 500 GeV centre-of-mass have been optimised in a similar fashion as for the 3 TeV version [2].

The basic parameters at the collision point are determined by the different accelerator systems:

- The bunch charge N and length σ_z are mainly a function of the linac design. The longitudinal single bunch wakefield makes the bunch length a function of the charge $\sigma_z(N)$ in order to limit the final beam energy spread.. The transverse wakefield effects then limit N, via the wakefield kick which is propotional to $NW_T(2\sigma_z)$.
- The horizontal emittance is mainly a function of the damping ring performance, with some contributions from other systems.
- The vertical emittance depends on damping ring and the transport from the damping ring to the interaction point.
- The effective vertical and horizontal beta functions are functions of the final focus system and have lower limits.

Some parameters have been chosen to be more relaxed than for CLIC at 3 TeV:

- Larger horizontal emittance at the interaction point of 2.4 μm instead of 0.66 μm has been assumed to relax the damping ring design requirements.
- Larger beta-functions have been assumed at the collision point to relax the beam delivery system requirements.

The bunch charge in the main linac has been chosen as for the 3 TeV case but taking into account that the machine is significantly shorter. This has two main consequences. First, this allows tolerating a constant local transverse wakefield kick, even at lower gradients. In case of the 3 TeV design the wakefield kick had to be reduced with the gradient since the length of the machine increased. Second, it allows having a factor of about two larger local wakefield kick from one bunch to the next than at 3 TeV. In addition, the requirement for the quality of the luminosity spectrum at the interaction point has been made more stringent, in order to make the degradation of the spectrum quality due to beam-beam effects and the unavoidable initial state radiation comparable. As a figure of merit we use the luminosity delivered within a band of ±1% around the nominal centre-of-mass energy.

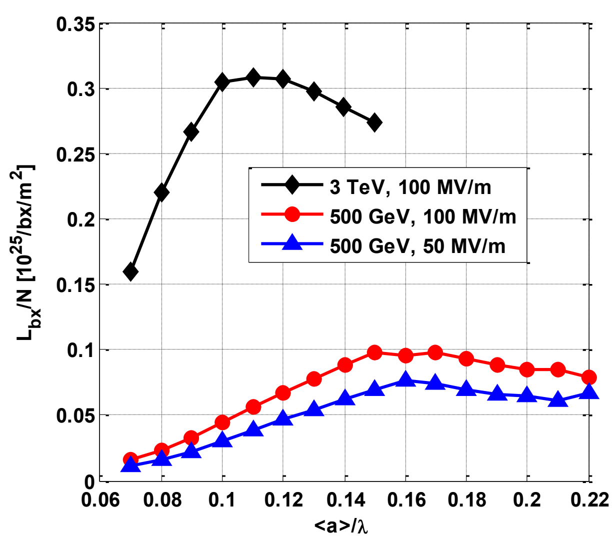

Figure 1: Luminosity per bunch crossing in 1% energy spectrum divided by the bunch population L_{bx}/N versus average aperture to the wavelength ratio $<a>/\lambda$ is plotted.

In order to illustrate the difference between the two cases of 3 TeV and 500 GeV, luminosity per bunch crossing in 1% energy spectrum divided by the bunch population L_{bx}/N versus average aperture to the wavelength ratio $<a>/\lambda$ is plotted in Fig. 1 for 3 difference cases: 3 TeV, $<E_{acc}>$ = 100 MV/m; 500 GeV, $<E_{acc}>$ = 100 MV/m; and 500 GeV, $<E_{acc}>$ = 50 MV/m. Black diamond curve represent the nominal case where the optimum $<a>/\lambda$ is 0.11. Using the nominal structures optimized for 3 TeV in the 500 GeV main linac would result in luminosity loss of about factor 6 from 0.3 to 0.05. This loss can be partially compensated by using accelerating structures with larger aperture since for 500 GeV the optimum $<a>/\lambda$ is close to 0.16. In addition, Fig. 1 shows the difference in the L_{bx}/N for 500 GeV between 100 MV/m and 50 MV/m accelerating gradients coming mainly from the linac length, red circles and blue triangles, respectively.

RF CONSTRAINTS

The following three rf constraints have been used in the optimization:

1. Surface electric field: $E_{surf}^{max} < 260$ MV/m
2. Pulsed surface heating: $\Delta T^{max} < 56$ K
3. Power: $P_{in} /C \cdot \tau_p^{1/3} \cdot f < 156$ MW/mm/ns$^{2/3}$

Here E_{surf}^{max} and ΔT^{max} refer to maximum surface electric field and maximum pulsed surface heating temperature rise in the structure respectively. P_{in}, τ_p and f denote input power, pulse length and frequency respectively. C is the circumference of the first regular iris. These constraints are the same as used in the optimization of the 3 TeV CLIC main linac accelerating structure [3,4]. This means that the structure high gradient performance is as challenging to achieve as for the 3 TeV case. In addition, two values for the rf phase advance per cell in the structure have been investigated: 2π/3 and 5π/6.

THREE TEV DESIGN CONSTRAINTS

In addition to the beam dynamics and rf constrains, there are a number of constraints which has to be applied to the 500 GeV CLIC if it would be built as the first stage of 3 TeV CLIC. There are several parameters fixed by the 3 TeV design: bunch separation N_s of 6 rf cycles, rf pulse length t_p of 242 ns and the structure active length L_s of 230 mm. These parameters can only be changed by factor 2 since it is related to the 3 TeV layout or to the rf frequency in the injectors. Finally the list of different cases studied in this paper is presented below:

1. N_s = free; L_s > 200 mm; t_p = free
2. N_s = 6; L_s = 230 mm; t_p = 242 ns
3. N_s = 6; L_s = 480 mm; t_p = 242 ns
4. N_s = 6; L_s = 480 mm; t_p = 483 ns

where the first case represents 500 GeV CLIC optimum without taking into account 3 TeV design constraints. It is used as a reference to indicate how much the performance is reduced due to the 3 TeV design constraints.

OPTIMIZATION RESULTS

The 500 GeV CLIC main linac accelerating structure optimization has been performed in a range of $<E_{acc}>$ from 50 to 100 MV/m always at 12 GHz. The figure of merit (FoM) $\eta L_{b\times}/N$ has been maximized as in [2,3], where η is rf-to-beam efficiency. For fixed centre-of-mass collision energy this quantity is proportional to the average luminosity divided by the average rf power which has to be provided for acceleration. Unfortunately, no cost model was available for 500 GeV CLIC optimization.

The results are presented in Fig. 2 where all 4 different combinations mentioned in the previous section has been analyzed for two different values of rf phase advance per cell and are marked as shown in the legend. In addition, two cases are presented which correspond to the 500 GeV CLIC built using nominal 3 TeV structure (CLIC_G [4]) at the nominal and double pulse lengths. Since the repletion rate is limited to multiples of 50 Hz, the luminosity in 1% energy spectrum calculated at 50 Hz for all the cases and normalized to the nominal luminosity in 1% energy spectrum at 3 TeV of 2×10^{34} cm^{-2}sec^{-1}[1] is plotted in Fig. 2(bottom) as a luminosity reduction factor. First Fig. 2(top) where FoM is presented clearly indicate that reduction of the gradient allows to design a structure which is better adapted to the 500 GeV CLIC (larger aperture). Second, in Fig. 2(bottom) there are two cases which are quite close to the red solid line which is the best case achieved where no 3 TeV constraints were applied. Let's consider 3 cases indicated in Fig. 2 by arrows:

1. Nominal structure but not nominal pulse length. This means the layout must be adapted. Luminosity is 3 times lower than nominal. Gradient is 80 MV/m.
2. Optimized structure of nominal length and nominal pulse length. This means the layout is nominal. Luminosity reduction is only factor 2. Gradient is 80 MV/m.
3. Optimized structure of double length and double pulse length. The layout is not nominal. Luminosity is the same as for 3 TeV case. Gradient is significantly lower: 50 MV/m.

The fact that layout is not nominal in the cases 1 and 3 means that it has to be rebuilt to a certain extent when upgrading from 500 GeV to 3 TeV. It is not necessary in the case 2. Case 3 gives nominal luminosity but the significantly lower gradient and consequently longer linac could have an impact on the cost which was not optimized in the present study. Finally case 2 has been chosen as a baseline configuration for 500 GeV CLIC. The luminosity reduction by factor 2 could be overcome potentially by increasing repetition rate from 50 to 100 Hz. The parameters of the optimum structure for 500 GeV are presented in Table 1 giving more details about its rf design and properties. One of the distinct features is larger aperture which allows transporting twice larger charge than nominal along the linac with acceptable emittance growth. The average gradient is lower but since the rf constraints were kept the same as for 3 TeV accelerating structure optimization the maximum surface electric and magnetic fields are as high as in the 3 TeV nominal structure [4].

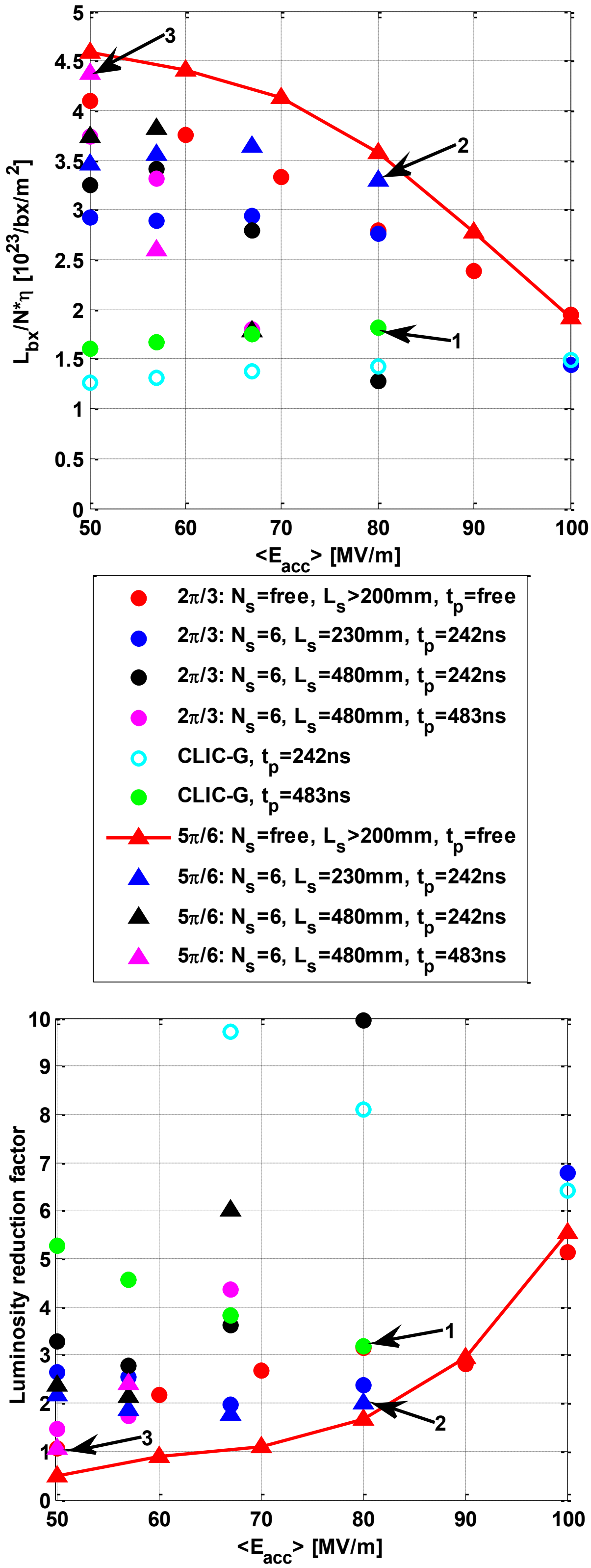

Figure 2: FoM (top) and luminosity reduction factor (bottom) are presented for 10 different sets of constraints described in the text and marked in the legend (middle).

Table 1: CLIC_502 Structure Parameters

Average loaded accelerating gradient	80 MV/m
Frequency	12 GHz
RF phase advance per cell	5π/6 rad.
Average iris radius to wavelength ratio	0.145
Input, Output iris radii	3.97, 3.28 mm
Input, Output iris thickness	2.08, 1.67 mm
Input, Output group velocity	1.88, 1.13 % of *c*
Number of regular cells	19
Structure length including couplers	230 mm (active)
Bunch spacing	0.5 ns
Bunch population	6.8×10^9
Number of bunches in the train	354
Filling time, rise time	50.3, 15.3 ns
Total pulse length	242 ns
Peak input power	74.2 MW
RF-to-beam efficiency	39.6 %
Maximum surface electric field	250 MV/m
Maximum pulsed surface heating temperature rise	56 K

CONCLUSIONS

The 500 GeV CLIC main linac accelerating structure optimization procedure taking into account complex interplay between beam dynamics and rf performance and 3 TeV design has been described. The results of optimization as well as the parameters of the optimum structures have been presented. The luminosity in a band of ±1% around the nominal energy can be increased from 6 times lower than nominal at 3 TeV up to only 2 times lower by using optimum accelerating structure.

REFERENCES

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