DESIGN OF AN ACCELERATING STRUCTURE FOR A 500 GeV CLIC USING ACE3P

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Abstract

An optimized design of the main linac accelerating structure for a 500 GeV first stage of CLIC is presented. A similar long-range wakefield suppression scheme as for 3 TeV CLIC based on heavy waveguide damping is adopted. The accelerating gradient for the lower energy machine is 80 MV/m. The 500 GeV design has larger aperture radius in order to increase the maximum bunch charge and length which is limited by the short-range wakefields. The cell geometries have been optimized using a new parametric optimizer for Ace3P and details of the RF cell design are described. Field parameters for the full structure are calculated using a power flow equation.

INTRODUCTION

One of the design options for the CLIC (Compact Linear Collider) is to first build a machine capable of 500 GeV center of mass energy, which can later be expanded to 3 TeV. The optimal accelerating structure for a 500 GeV accelerator is slightly different from the current 3 TeV design CLIC-G [2], even if the topology is shared. This is due to a higher bunch charge, partly compensated by relaxing the transverse wakefield limit due to the shorter linac length.

This paper presents a RF design for the structure CLIC-502, which is optimized for operation in a 500 GeV CLIC. The detail of the geometry and RF computations is at a level where it is soon possible to build a prototype of the structure, which was originally presented in an earlier design stage at LINAC'10 [1].

DESIGN OF SINGLE CELLS

The geometry of three single cells named “first”, “middle”, and “last” was varied using the parameters shown in Fig. 1 in order to minimize the peak surface field to gradient ratios. The iris aperture radius \(a\) and thickness \(d\) were fixed based on short range wake field limits, while the outer wall parameters \(e_{\text{ow}}\, c\), and iris parameters \(e\) and \(s_{\text{Fr}}\) were varied. For each of these combination of parameters, the cell radius \(b\) was tuned in order to have the correct frequency \(f_0\) = 11.994 GHz for the TM_{01} like mode at 150° RF phase advance per cell. The final design of these single cells were then combined in order to get the full structure, as described in the next section.

The calculation of the surface fields and other RF parameters were made using the finite element eigenmode solver Omega3P [4]. An separate program, AcdOptiGui [5], was used to steer the calculations and post-processing. The
were similarly varied in order to minimize the peak surface electric field and the modified Poynting vector $S_{c}$ [3]. It was quickly found that these fields were very weak functions of $sFrac$, which was therefore locked at a small value. The relative deviations from the minimum fields were then plotted as for the outer wall, and an approximate optimum taking both minima into account selected.

Having the final geometry parameters for a cell, several calculations with different mesh using both E- and H-formulation were performed in order to check convergence. The means of the resulting field parameters from these calculations were taken as the final value for the field parameters, and the error estimate used was $\pm 1.96 \cdot \sqrt{\text{variance}/n}$. The results are shown in Table 2.

In all cells the magnetic field as a function of the outer wall parameters had a similar structure as the one shown in Fig. 2, with a broad minimum depending on both parameters. A set of parameter values were first chosen for the first and last cell, using the same value for $c$ now but different values of $b$, and avoiding the region of rapid rise in the upper-right corner of the plot, which is due to field concentration on the damping waveguide entrances.

For the irises, both the electric field and $S_{c}$ were roughly parabolic functions of $c$, with the electric field smallest for smaller values of $c$ than $S_{c}$. This is due to the electric field being largest in the case of a “pointy” iris, while $S_{c}$ grows if the electric field is spread into the regions where the magnetic field is non-negligible. It was also seen that the minimum $S_{c}$ was lower for smaller iris apertures which has longer iris to outer wall distance.

For the middle cell, it was chosen to set all parameters except $b$ as the average between the first and last cell. This choice was verified by varying the parameters, and found satisfactory. This makes the tapering linear, making for a less complicated full structure geometry.

**FIELDS IN COMPLETE STRUCTURE**

The data for the three single cells described above was used to interpolate their relative field parameters along a complete structure, which was then used to calculate the power flow and absolute fields, using a continuous analytic approach for the steady-state fields [7]. The relative fields at $z = 0$ was fixed at the parameters for the “first” cell, the fields at $z = N_{\text{cells}} \cdot L$ at the “last” cell parameters, and $z = N_{\text{cells}} \cdot L + L$ at the “middle” cell, where $N_{\text{cells}}$ is the number of cells for the structure.

The pulsed surface heating temperature increase was calculated using Equation (3.36) and OFE copper data from [8], describing the temperature increase due to surface currents induced by RF pulses on the surface of a relatively flat and thick conductor. The assumed pulse was piece-wise linear in power, with first a linear rise from $P = 0$ to $P_{\text{rise}}$ in time $t_{\text{rise}} = 15.3 \text{ns}$, followed by continued increase to $P_{\text{in}}$ in time $t_{\text{fill}} = \int_{0}^{L} \frac{dz\prime}{\eta_{z}(z')}$, flat-top of length $t_{\text{beam}} = t_{\text{bunch}} \cdot N_{\text{bunches}}$, linear decline to $P_{\text{rise}}$ in $t_{\text{fill}}$, and finally decline to $P = 0$ in $t_{\text{fill}}$. Here $t_{\text{rise}}$ was assumed to be the same as in [1], and $P_{\text{rise}}$ as the power at the beginning of the beam-loading compensation ramp described in [7].

The number of cells was assumed to be 22, such that the structure length would be the approximately equal to $L = 150 \text{ MV/m}$ and $\max(\Delta T) = 56 \text{ K}$ [1]. We see that the RF parameters found are more-or-less identical to what were found here, except for $\Delta T$. The increase in number of regular cells is possible because this structure is likely to be built with compact couplers, where the end cells also couple the power in and out of the structure. These cells are assumed to have similar properties as regular cells, and should thus not make a large difference on the RF parameters.

| Number of cells $N_{\text{cells}}$ | 22 |
| Active length | 229 mm |
| Peak/steady-state $P_{\text{in}}$ | 74.2 MW |
| Average loaded $E_{\text{acc}}$ | 80 MV/m |
| $\max(|E|_{\text{surf loaded}})$ | 217 MV/m |
| $\max(|E|_{\text{surf unloaded}})$ | 227 MV/m |
| $\max(\Delta T_{\text{loaded}})$ | 41 K |
| $\max(\Delta T_{\text{unloaded}})$ | 46 K |
| $\max(S_{c})$ | 4.61 MW/µm² |
| RF → beam efficiency $\eta$ | 39.6% |
| $t_{\text{fill}}$ | 48.0 ns |
| Bunch separation $t_{\text{bunch}}$ | 0.5 ns |
| $N_{\text{bunches}}$ | 354 |
| Bunch population $N_{\text{particles}}$ | 6.8 \cdot 10^9 $e^\pm$ |

The final result is clearly within RF constraints of $\max(|E|_{\text{surf}}) < 260 \text{ MV/m and } \max(\Delta T) < 56 \text{ K}$ [1]. Comparing to CLIC G which has $\max(S_{c}) = 5.7 \text{ MV/m}$ and $P/C = P/(2\pi a) = 3.10 \text{ MW/mm}$ at first iris, CLIC$_{502}$ reaches lower values, with $P/C = 2.97 \text{ MW/mm}$.

**WAKEFIELDS**

The maximum permitted single-bunch transverse wakefield at the 2nd bunch is given by $W_{\perp,\text{max}} \cdot N_{\text{particles}} = \frac{C \times 4 \cdot 10^6 E_{\perp}}{150 \text{ MV/m}}$, where the constant $C$ is increased from 10 V/pC/mm/m for the 3 TeV case to 20 V/pC/mm/m due to

![Figure 3: The new structure’s gradient and peak fields at flattop, and peak temperature increase along structure in loaded (continuous lines) and unloaded (dashed) case.](image-url)
The design of the CLIC,502 accelerating structure has been refined to a higher detail level. Most of the RF parameters are close to what was found by the initial study [1], except $\Delta T$. An early estimate of the wakefields in the structure has also been done, indicating that the damping might need to be increased. Finally, a parametric interface and data management program for Omega3P was developed, improving the workflow for geometry optimization using Omega3P.

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REFERENCES


