

ANALYSIS OF LONG-RANGE WAKEFIELDS IN CLIC MAIN LINAC ACCELERATING STRUCTURES WITH DAMPING LOADS

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Abstract

The baseline design of the CLIC accelerating structure foresees a moderate detuning and heavy damping of high order modes (HOMs), which are the source of long-range transverse wakefields. Such unwanted fields produce bunch-to-bunch instabilities so the HOMs must be suppressed. In order to damp these modes, the CLIC RF structure is equipped with lossy material inserted into four rectangular waveguides coupled to each accelerating cell. The lossy material absorbs EM (electromagnetic) wave energy with little reflection back to the accelerating cells. In the past, computations of the long-range wake of CLIC accelerating modes have been done using perfectly absorbing boundaries to terminate the damping waveguides. In this paper, 3D EM simulations of CLIC baseline accelerating structure with HOMs damping loads will be presented. A comparison between different EM codes (GdfidL, CST PARTICLE STUDIO[®]) will be discussed as well as the analysis of different types of absorbing materials with respect to the wakefields damping.

INTRODUCTION

The CLIC accelerating structure parameters follow the baseline design reported in [1]. Figure 1 shows the vacuum part of the 3D geometry of one CLIC RF accelerating structure, which is composed of a tapered chain of 26 damped cells with a double-feed coupler for the input and the output power. The cells geometry varies along the length of the accelerating structure in a way that the synchronous phase advance at the operating frequency of 11.994 GHz is always c . The cells vary in iris radius (3.15 to 2.35 mm) and iris thickness (1.67 to 1.00 mm). The total length of one accelerating structure is about 25 cm and the transverse dimensions fit in a circle of 10 cm radius. Each cell is equipped with four rectangular waveguides in order to heavily damp the HOMs.

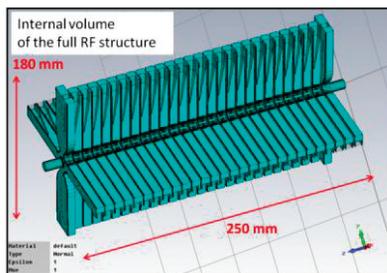


Figure 1 : CLIC travelling wave accelerating structure.

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Figure 2 shows the shape of the loads used to terminate the damping waveguides. The distance between the beam axis and the tip of the SiC load is 50 mm. The load has 30 mm long part which is tapered from 1x1 mm cross-section to 5.6x5.5 mm and a 10 mm long part of the latter cross-section [1]. The aim of this work is to verify the baseline design for the real geometry i.e. with damping loads made of realistic lossy material.

Different materials have been investigated for their lossy characteristics such as CerasicB1, EkasicF and EkasicP. The EM properties have been measured in the past for some frequency points. The choice of the material for the damping loads is a compromise between EM properties and cost. It turned out that the better material (CerasicB1) is more expensive. More details about measurements of EM properties can be found in [2].

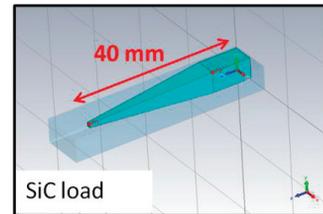


Figure 2 : Geometry of damping load into the waveguide.

SIMULATIONS SETUP

Material Models

Measurements of the permittivity of materials have shown that they are almost constant in the frequency range of interest (10 to 40 GHz).

Different material models have been used in GdfidL [3] and CST Particle Studio[®] [4] in order to study the effect on wakefields of different materials and in order to benchmark the two EM codes.

The simpler way to introduce dispersive material in GdfidL is a constant conductivity model. The analytical formulation is shown in equation 1. The conductivity is calculated at a certain frequency for a specific value of the loss tangent and real part of permittivity. The loss tangent in the full range of frequencies is calculated by inverting equation 1 which gives dependence with the inverse of frequency.

In GdfidL the permittivity can also be expressed with an N -th order Lorentz medium with resonant angular frequencies ω_n and damping angular frequencies γ_n (see eq. 2). This last model has been adopted for the GdfidL simulations for the comparison presented in this report. CST PS[®] in the version 2011 provides the Lorentz

medium with only two resonances and for this reason a first order (single pole) Debye model has been used. The permittivity of such a material goes down as the frequency is increased (see eq. 3). These last two models are the best we can do to fit the measured points (see Fig. 3).

$$\sigma = \tan\delta \cdot 2\pi f \cdot \varepsilon \quad (1)$$

$$\varepsilon(\omega) = \varepsilon_\infty + \varepsilon_\infty^2 \sum_{n=1}^N \frac{A_n \omega_n^2}{\omega_n^2 + i\omega\gamma_n - \omega^2} \quad (2)$$

$$\varepsilon(\omega) = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + i\omega\tau} \quad (3)$$

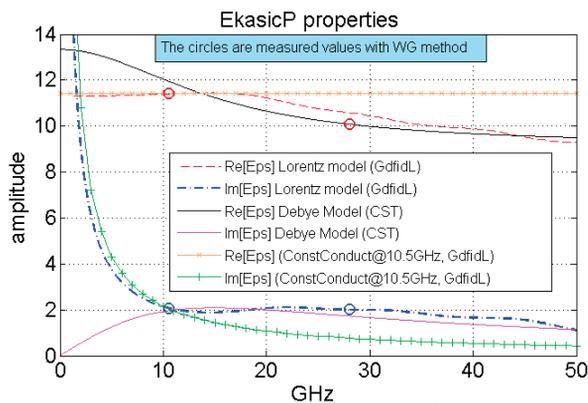


Figure 3 : Permittivity used in CST PS[®] and GdfidL.

GdfidL Simulations

GdfidL computes electromagnetic fields in 3D structures using parallel or scalar computers [3]. An important feature for a successful simulation is the discretization of the computational volume. In order to achieve reliable results, a study of the density and number of meshes is necessary. Different simulations have been performed with 100 μm and 50 μm mesh steps. This analysis has shown that it is necessary to use 50 μm mesh step in (x, y, z) axes. A simulation at 25 μm mesh step along z axis has been performed and no important variation in the wakefields has been observed respect to the case of 50 μm .

Furthermore additional mesh planes have been used in the location of the iris of the accelerating cells in order to better describe the geometry.

The possibility to use the distributed computing has led us to an extensive use of GdfidL. With the mesh size described above the maximum length of wakefield which can be obtained with our distributed system is 2.6 meters with 50 μm mesh step in all directions (x, y, z). The simulations stop after two weeks because of a specific policy on the wall clock time that cannot be changed by the user. The optimum would have been to cover all CLIC bunch train i.e. about 47 m, but it is not yet possible with such a system.

Figure 4 shows the envelope of the absolute value of the wakefields using the EkasicP with two different

models: the Lorentz model (four resonances) and the constant conductivity model. Furthermore also perfect matching loads (PML) have been added in the comparison. It represents the best case one could achieve because the loads absorb all incoming EM energy.

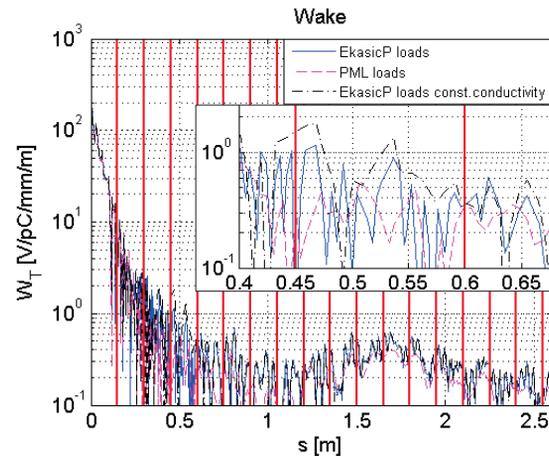


Figure 4 : Transverse wakefields in CLIC accelerating structure for different representations of load material calculated using GdfidL. The vertical asymptotes show the position of CLIC bunches.

The differences in the wakefields between the Lorentz model and the constant conductivity model show the importance of the material model choice. In the ranges from 0 m to 0.4 m and from 0.7 m to 2.6 m there are no significant differences between the two models. Instead, between 0.4 m and 0.7 m the wakefields in the case of constant conductivity model are higher than the case of Lorentz model.

The amplitude of wakefields with EkasicP (both models) is the same as the case of PML up to the position of the CLIC second bunch that sits at 0.15 m. After that, the PML has in general lower reflections respect to EkasicP and consequently lower wakefield amplitude. This is due to a 21.6 GHz resonance with a high quality factor value as can be seen in the real part of transverse impedance (see Fig. 5). For this reason an improvement of the design of the loads is necessary.

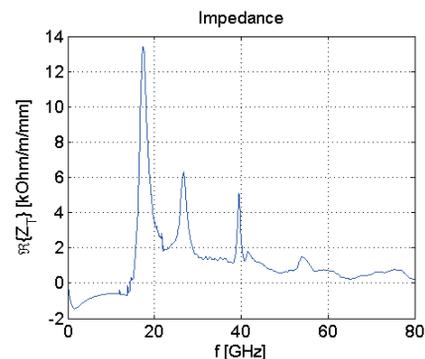


Figure 5 : Transverse impedance of the accelerating structure. The loads are made of EkasicP.

Simulation of wakefields with EkasicF has been performed as well and despite of the lower loss tangent (see Fig. 6) with respect to EkasicP, no significant differences in the wakefield amplitude have been observed.

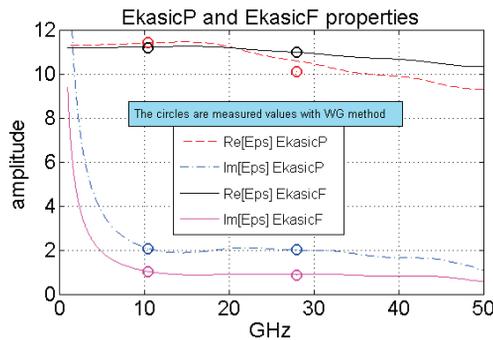


Figure 6 : Permittivity of EkasicF and EkasicP.

CST Particle Studio® Simulations

In CST PS® a convergence study has been carried by considering the difference between the integrals of the wakefields for two simulations with different number of mesh-line per wavelength (see Fig. 7). The simulated geometry is the middle cell of the CLIC accelerating structure.

It is to be noted that the mesh type also influences the convergence. Hexahedral meshes were used in the time domain wakefields solver which only supports this kind of meshes. In general, in the case of tetrahedral meshes the convergence is smoother.

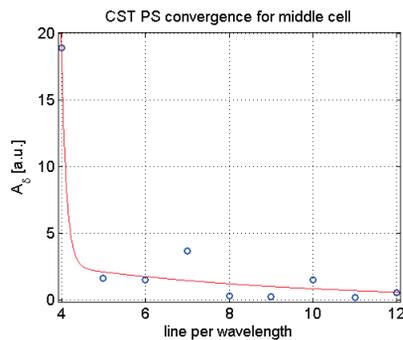


Figure 7 : CST PS® convergence study.

The EM simulations have been performed on a 128 GB RAM, 24 CPUs (X5650) @ 2.67 GHz, 2660 MHz, 6 core machine. The discretization of the structure geometry have been done by using 5 lines per wavelength which are equivalent to 5.9 line per sigma RMS bunch length in GdfidL. This results in 819 M hexahedral meshes and (852, 851, 1133) mesh planes in x, y, z directions (Nx, Ny, Nz). A bunch length of 1.2 mm has been used in both EM codes. Figure 8 shows a good agreement between the two EM codes up to the CLIC second bunch position.

The total simulated wakefields was 0.68 m which took 47 hours. Most likely a very good match between the two codes would have been reached by increasing the mesh

density. This solution has not been done because it would have required a more powerful machine or a parallelization. GdfidL simulations have been performed in less time because of the possibility to use a distributed computing.

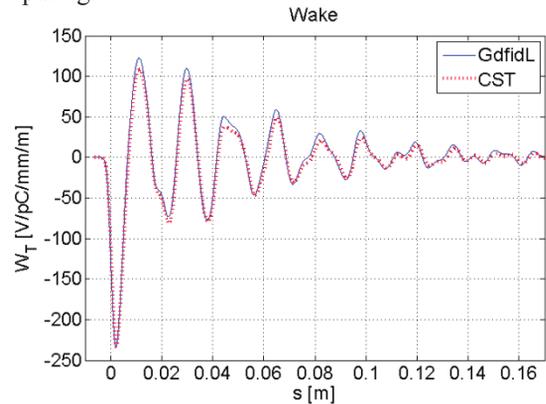


Figure 8 : Transverse wakefields in CLIC accelerating structure with EkasicP loads. Comparison between GdfidL and CST PS®.

CONCLUSIONS

The two EM codes CST PS® and GdfidL have been compared simulating transverse wakefields in CLIC accelerating structure baseline design. Good agreement has been found. Extensive numerical study has been done with GdfidL to find the right parameters for the wakefields simulation in CLIC baseline accelerating structure with HOM loads made from realistic damping material.

The comparison of wakefields by using different material representations has shown the importance of implementing the right model for the material of damping loads. EkasicP (Lorentz model) shows higher wakefields amplitude than PML after the position of the CLIC second bunch but is much better of the EkasicP (const.conduct.) particularly in the range 0.4-0.7 m. No considerable differences have been noted in the wakefields amplitude up to 2.6 m for EkasicP and EkasicF.

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