

DESIGN OF AN X-BAND ACCELERATING STRUCTURE FOR THE CLIC MAIN LINAC

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Abstract

The rf design of an accelerating structure for the CLIC main linac is presented. The 12 GHz structure is designed to provide 100 MV/m average accelerating gradient with an rf-to-beam efficiency as high as 27.7 %. The design takes into account both aperture limitations and HOM-suppression requirements coming from beam dynamics as well as constraints related to rf breakdown and pulsed surface heating.

INTRODUCTION

Recently the CLIC study has changed the operating frequency and accelerating gradient of the main linac from 30 GHz and 150 MV/m to 12 GHz and 100 MV/m respectively. This major change of parameters has been driven by the results of a main linac cost and performance optimization [1]. A new set of overall CLIC parameters is under preparation [2]. In this report, the rf design of the new X-band accelerating structure for the CLIC main linac is presented.

RF DESIGN AND OPTIMIZATION

Frequency and gradient are the key parameters for any accelerating structure. Following their major change fundamental issues ranging from the basic rf design of the cell to the structure rf design and optimization procedure have been revisited.

Basic Cell Geometry and HOM Damping

The basic cell geometry and heavy damping developed for 30 GHz CLIC structures have been carried over into the X-band CLIC structures. However the reduction in frequency by factor 2.5 and, even more importantly, the gradient reduction by factor 1.5 results in an overall reduction of the pulsed surface heating temperature rise ΔT^{\max} of $1.5^2 \cdot 2.5^{1/2} \approx 3.6$ in a scaled structure at the same pulse length. Because of this the old structure design, which was based on hybrid slotted iris plus waveguide damping, was not simply scaled [3] to the new frequency keeping pulse length the same. Instead the decrease in the pulsed surface heating was used to eliminating the iris slots, and compensating by opening the damping waveguide coupling aperture. The first measure reduces the maximum surface fields on the iris and consequently increases the high gradient potential, on one hand, but degrades the HOM damping because of the absence of slots, on the other hand. The second measure improves the waveguide damping to the required level but reduces the surface of the outer cell wall and thus increases the temperature rise which, nevertheless, still remains acceptable. The basic cell geometry after these modifications is shown in Fig. 1. The wakefield damping

waveguides result in a lowest dipole-band Q of below ten. The cell has an elliptical cross section iris and convex elliptical cross-section outer walls in order to minimize surface fields. The four damping waveguides are terminated with broadband loads which are not shown in Fig. 1. This geometry is very close to the one which has been already proposed as the nominal CLIC accelerating structure design [4].

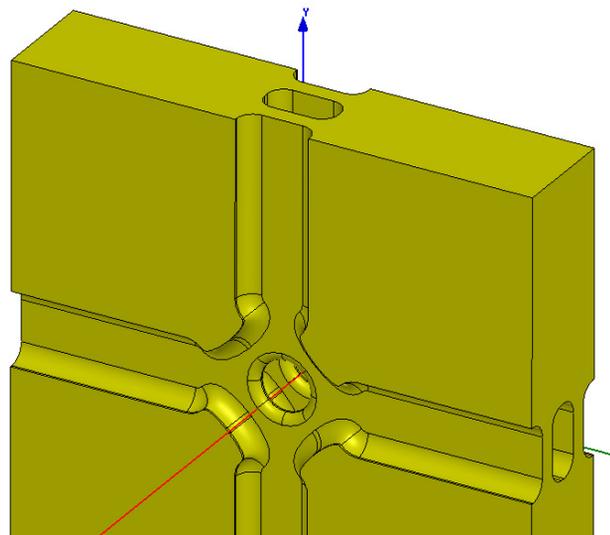


Figure 1: Basic cell geometry of the accelerating structure with strong waveguide HOM damping.

RF Constraints for X-band Copper Structures

A significant effort has been made to collect as many additional X-band experimental data points as possible beyond those that have been used in [1] in order to refine the rf constraints for copper structures. Based mainly on the NLC/JLC X-band program [5] many new unpublished data points have been collected via private communications with SLAC colleagues [6]. All the collected data is summarized in [7]. Based on the high gradient performance of X-band travelling-wave accelerating structures with rf phase advance per cell of 120 and 150 degree the two rf constraints (1) and (3) used in [1] have been updated to:

1. Surface electric field: $E_{surf}^{\max} < 260$ MV/m
2. Pulsed surface heating: $\Delta T^{\max} < 56$ K
3. Power: $P_{in}/C\tau_p^{1/3} < 18$ MW/mm \cdot ns $^{1/3}$

Here E_{surf}^{\max} refers to maximum surface electric field in the structure, P_{in} refers to input power and τ_p refers to pulse length. C is the circumference of the first regular iris. This set of rf constraints has been used in the rf design and optimization of the CLIC X-band accelerating structure which is described in the next section.

Structure Optimization

Essentially the same optimization procedure as used in [1] has been applied for the final structure optimization except the frequency and the gradient were fixed and the values used for two of the high-power constraints were changed as described in the previous section. Fixing frequency and gradient allowed a significant reduction in the step size by which the other free parameters of the structure were varied. These parameters include first and last iris radius and thickness, structure length and pulse length. In addition 120 and 150 degree per cell phase advance were compared. The optimisation was made twice, once with performance and once with cost as the final criterion. No advantage was observed both in performance and in cost for 150 degree phase advance so the classical value of 120 degree has been chosen. On the other hand, the choice of the structure length was not so clear because the optimum length of for cost was 18 cm and the optimum length for performance was 30 cm. A structure active length of 23 cm was chosen as a compromise.

STRUCTURE PARAMETERS

Table 1: CLIC_G Structure Parameters

| | |
|---|---------------------|
| Average loaded accelerating gradient | 100 MV/m |
| Frequency | 12 GHz |
| RF phase advance per cell | $2\pi/3$ rad. |
| Average iris radius to wavelength ratio | 0.11 |
| Input, Output iris radii | 3.15, 2.35 mm |
| Input, Output iris thickness | 1.67, 1.00 mm |
| Input, Output group velocity | 1.66, 0.83 % of c |
| First and last cell Q-factor (Cu) | 6100, 6265 |
| First and last cell shunt impedance | 89, 112 $M\Omega/m$ |
| Number of regular cells | 24 |
| Structure length including couplers | 230 mm (active) |
| Bunch spacing | 0.5 ns |
| Bunch population | 3.7×10^9 |
| Number of bunches in the train | 312 |
| Filling time, rise time | 62.9, 22.4 ns |
| Total pulse length | 240.8 ns |
| Peak input power | 63.8 MW |
| RF-to-beam efficiency | 27.7 % |
| Maximum surface electric field | 245 MV/m |
| Maximum pulsed surface heating temperature rise | 53 K |

After a few iterations of the optimization which also took into account feed-back from other CLIC sub-systems, a final set of parameters for main linac accelerating structures emerged under the name CLIC_G.

Technology

The main parameters of the structure are presented in Table 1. Several issues are worth emphasising. Firstly, following beam dynamics requirements, the optimum average aperture radius to wavelength ratio is 0.11 resulting in the group velocity reaching in the last cell 0.83 % v_g/c . At this rather low group velocity, the bandwidth of the structure sets a lower limit to the rise time of the field level in a cell in the same way as in a high Q cavity. This rise-time limit is also shown in the Table 1 together with the conventional filling time of a travelling-wave structure. The consequence of the limited bandwidth is that two ramps are necessary at the beginning of the pulse to simultaneously compensate for the structure bandwidth and for the beam loading induced bunch to bunch energy spread. The input pulse shape is shown in Fig. 2.

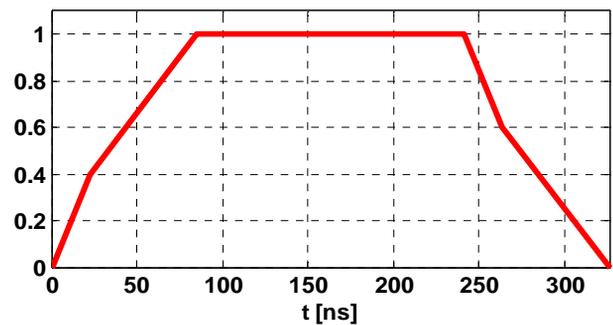


Figure 2: Schematic shape of the input pulse for CLIC_G.

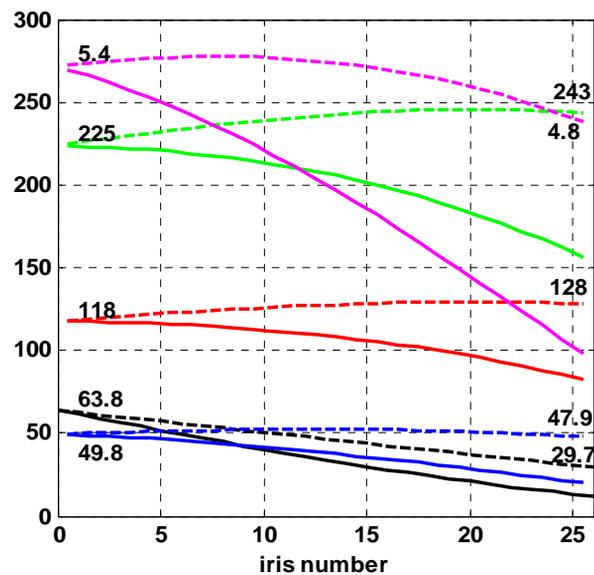


Figure 3: The fundamental mode properties of the nominal CLIC accelerating structure, CLIC_G. The traces from top to bottom are: $S_c * 40$ [$W/\mu m^2$](pink), surface electric field [MV/m](green), accelerating gradient [MV/m](red), power [MW](black), pulse surface temperature rise [K](blue). Dashed traces are unloaded and solid are beam loaded conditions.

Secondly, both the iris radius and thickness are tapered linearly in order to provide an optimum distribution of

various high-power parameters and to avoid the hot spots along the structure. Distributions of these parameters are shown in Fig. 3. The unloaded structure gradient and the surface electric field rise slightly towards the end. The temperature rise is made to be constant because it is the dominant high-power constraint for the present type of HOM damping. In Fig. 3, the pink line shows the distribution of a new field quantity S_c [7] which serves as a limit for high gradient performance and to certain extent combines both the power and the surface electric field constraints. Though it was not directly implemented in the optimization algorithm, its distribution looks reasonable and its maximum value of $5.5 \text{ W}/\mu\text{m}^2$ is rather close to experimental observations summarized in [7]. Several prototypes of the CLIC_G structure without and with damping features are currently under fabrication and planned to be tested soon [8].

Table 2: Parameters of the lowest dipole-band modes in CLIC_G

| Cell | First | Middle | Last |
|-----------------------|-------|--------|-------|
| Q-factor | 10 | 7.7 | 6.3 |
| Amplitude [V/pC/mm/m] | 117 | 140 | 156 |
| Frequency [GHz] | 16.74 | 17.21 | 17.67 |

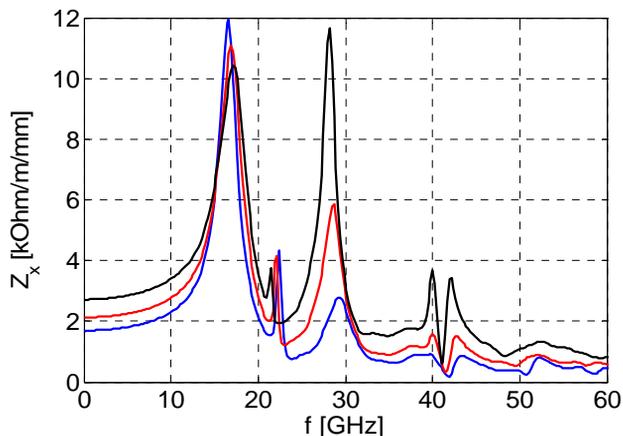


Figure 4: Transverse impedances of the first (blue), middle (red) and last (black) cells of the CLIC_G structure.

The tapering also provides detuning of the higher order modes which is an important effect even for heavily damped structures. The relative contributions of the heavy damping and detuning to the transverse wakefield spectrum is shown in Fig. 4. Parameters of the lowest dipole-band modes calculated from the fitting to the impedance curves are listed in Table 2. The transverse wake of the full structure was computed in time domain using parallel code GdfidL [9] is the result is shown in

Fig 5. One can see that the wake at the position of the second bunch is below the $7 \text{ V}/\text{pC}/\text{mm}/\text{m}$, as required for beam dynamics.

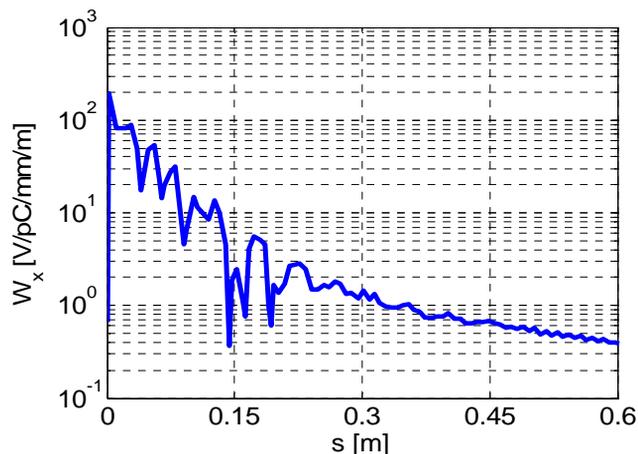


Figure 5: The envelope of the transverse wake of the CLIC_G structure. The CLIC bunch spacing is 0.15 m.

CONCLUSIONS

A new X-band CLIC main linac accelerating structure has been designed taking into account complex interplay between beam dynamics, rf performance and the overall machine cost. The new structure provides rf-to-beam efficiency of 27.7 % and strong HOM damping which has been validated by full scale time domain simulations.

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