PROGRESS IN THE DESIGN OF A DAMPED AND TAPERED ACCELERATING STRUCTURE FOR CLIC

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Abstract

Two of the main requirements for CLIC 30 GHz accelerating structures are an average accelerating gradient of 150 MV/m and features which suppress long-range transverse and longitudinal wakefields. The main effects that constrain the design of a copper structure are a surface electric field limit of about 300 MV/m, from evidence produced by the CLIC high-gradient testing program, and a pulsed surface heating temperature rise limit estimated to be of the order of 100 K. The interplay between maximum surface electric field, maximum surface magnetic field, transverse-wakefield suppression and RF-to-beam efficiency has been studied in detail. Several structures with a 110 ^{o} phase advance and rather constant peak surface electric field distributions have been designed. Different damping-waveguide geometries and waveguide-to-cavity couplings are compared.

1 INTRODUCTION

The choice of an average loaded gradient of 150 MV/m for the CLIC 30 GHz main linac accelerating structure and the necessity to suppress the wakefields result in large surface electric fields and pulsed surface heating temperatures. Minimizing these values has been chosen as key design criteria based on experimental observation of erosion due to RF breakdown [1] and calculation and observation of cracking due to pulsed surface heating [2, 3].

In our previous studies [4], a $2\pi/3$-quasi-constant gradient 84-cell copper structure called XDS (conveX Damped Structure) was designed with an elliptical cross-section for the cell-to-cell irises. For a given iris thickness and radius, such a profile allowed to reduce the ratio of the peak surface electric field to the accelerating gradient E_{peak}/E_{acc}. Heavy damping of the higher-order modes to provide wakefields suppression was achieved by coupling each cell to a set of four identical radial T-cross waveguides. The convex outer-wall profile of the cells was optimized to reduce the ratio of the peak surface magnetic field to the accelerating gradient H_{peak}/E_{acc}(see Figure 1 for the topology of the cells). The maximum unloaded surface electric field decreased from 400 MV/m at the head of the structure to 320 MV/m at the end whereas the maximum unloaded temperature rise increased from 120 K to 154 K (with a 121 ns pulse length and assuming that the thermal and electrical conductivity as well as the thermal diffusivity is constant during the pulse length). These values present a substantial improvement compared to the one of an older design [5] but are still too high for copper. The amplitude of the transverse wakefields at the second bunch was also too high (90 V/pC/mm/m).

To reduce further the peak surface electric and magnetic fields, a phase advance of 110 ^{o} was selected along with a suitable tapering of the iris thickness and radius. Several geometries of the damping waveguide and of the waveguide-to-cavity coupling were jointly studied aiming at rather constant unloaded peak electric field and maximum temperature rise distributions along the structure as well as reduced amplitudes of the transverse wakefields. The main outcome of these studies is a 77-cell structure with a peak surface unloaded electric field of about 350 MV/m, a constant pulsed heating temperature rise of about 120 K, an RF-to-beam efficiency of 24 % and an amplitude of the transverse wakefields of 45 V/pC/mm/m at the second bunch.

Figure 1: Topology of the XDSs cell and damping waveguides.

2 SOME DESIGN CONSIDERATIONS

The parametric studies performed on constant-impedance classical accelerating structures (no damping waveguides) [6] showed that, for a fixed iris radius and thickness, E_{peak}/E_{acc} is reduced when the phase advance is lowered. However, the shunt impedance also decreases, which has the adverse effect of reducing the RF-to-beam efficiency. A 110 ^{o} phase advance is therefore considered as a good compromise between a $\pi/2$ phase advance, which would lead to a structure requiring a higher input power, and the $2\pi/3$ phase advance adopted in [4]. The 110 ^{o} phase advance is also advantageous since, for an

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iris thickness ranging from 0.8 mm to 0.55 mm and an iris radius varying between 1.5 mm and 2.0 mm, the H_{peak}/E_{acc} ratios do not vary too much from their $2\pi/3$ phase advance values.

Unlike the studies reported in [4], the new XDSs have iris thicknesses that are kept constant or decrease linearly along the structure. However, the iris radius is still tapered linearly from 2.0 to 1.5 mm. In the absence of damping waveguides, H_{peak}/E_{acc} decreases then strongly along the structure. The waveguide-to-cell couplings can therefore be increased along the structures while maintaining H_{peak}/E_{acc} within acceptable values. Consequently, the cell Qs of the lowest dipole band also decrease along the structure.

3 DESIGN STUDIES

The first 110 º phase advance structure (XDSa) design has a cell-to-cell iris radius varying linearly from 2.0 mm to 1.5 mm, as in [4], and a constant iris thickness of 0.8 mm. The cross-section of the tip of the irises is elliptical and has an eccentricity of 1.8. The damping T-cross waveguides are dimensioned so that the cutoff frequency of the first propagating mode is 32.3 GHz, above the 29.985 GHz fundamental but below all the higher order modes. The waveguide-to-cell coupling irises are identical all along the structure and are 3.0 mm wide. E_{peak}/E_{acc} varies from 2.21 for the first cell to 1.80 for the last cell. The optimization of the convex outer-wall shape, a combination of straight and elliptical sections, gives a ratio H_{peak}/E_{acc} which decreases from 4.50 mA/V to 4.21 mA/V for the first and last cells, respectively. The variation of Q, R'/Q and v_g/c is summarized in Table 1.

Table 1: Fundamental mode parameters of the first, middle and last cell – XDSa

	Q	R'/Q (kΩ/m)	v_g/c (%)
First cell	3387	24.1	7.66
Middle cell	3342	27.9	5.24
Last cell	3292	32.1	3.25

The unloaded peak surface electric fields of the first and last cells are equal when the structure consists of 65 cells whereas the unloaded maximum temperature rises are similar for 90 cells (see Figure 2). The variation of the RF-to-beam efficiency with the number of cells shows a maximum of 26 % for 122 cells. For an 83-cell structure, the peak surface electric field decreases from 349 (first cell) to 316 MV/m (last cell), the pulsed temperature rise increases from 121 to 130 K and the RF-to-beam efficiency is 25 %. The dipole Qs computed with GdifdL [7] for the lowest dipole band are 53, 45 and 40 for the first, middle and last cell, respectively, giving an amplitude of the transverse wakes at the second bunch of 65 V/pC/mm/m.

To improve the damping of the transverse dipole modes, a 110 º phase advance structure (XDSb) has been designed such that the width of the waveguide-to-cell coupling iris increases from 3.0 mm for the first cell to 3.2 mm for the last one. With a variation of the iris thickness from 0.8 mm to 0.55 mm, the minimum thickness that ensures mechanical rigidity, the ratio H_{peak}/E_{acc} is equal to 4.17 mA/V for the last cell, slightly lower than in XDSa. E_{peak}/E_{acc} of the last cell increases to 2.00. Due to the tapering of the cell-to-cell iris thickness, the T-cross damping waveguides have to be designed for each cell. The dimensions were chosen so that the cutoff frequency of the their fundamental mode is 32.3 GHz. Table 2 shows the Q, R'/Q and v_g/c for the middle and last cells, the first cell being identical to the one of the XDSa.

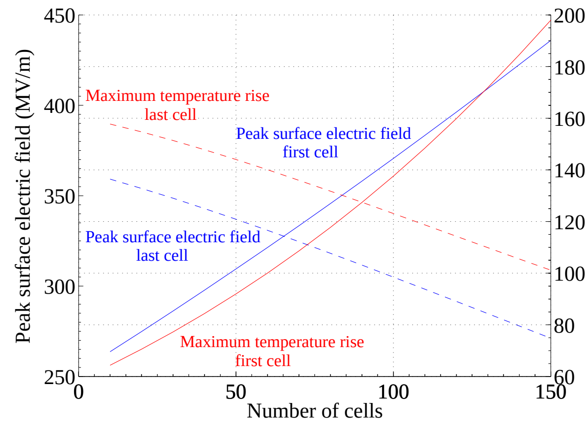

Figure 2: Unloaded peak surface electric field and maximum temperature rises for the first (- -) and last cells (—) vs. number of cells – XDSa.

Table 2: Fundamental mode parameters of the first, middle and last cells – XDSb

	Q	R'/Q (kΩ/m)	v_g/c (%)
First cell	3387	24.1	7.66
Middle cell	3379	28.4	5.61
Last cell	3365	33.2	3.84

Compared with the XDSa, the slower decrease of the ratio E_{peak}/E_{acc} combined with a similar variation of the ratio H_{peak}/E_{acc} presents the advantage that there is a range of number of cells for which both the unloaded peak surface electric field and the maximum temperature rise are rather constant along the structure (see Figure 3). For an 83-cell structure, the peak surface electric field is about 355 MV/m and the maximum temperature rise is 122 K. The RF-to-beam efficiency is about 25 % whereas a 130-cell structure would have the maximum efficiency of 27 %.

Due to the increase of the waveguide-to-cell iris width, the Qs associated with the lowest dipole band are now 31 and 24 for the middle and last cells. The amplitude of the transverse wakefields at the second bunch is reduced to 58 V/pC/mm/m.

A better damping of the transverse dipole modes can be achieved by increasing further the coupling between the cells and their damping waveguides. An increase of the waveguide-to-cell coupling iris width would however lead to higher H_{peak}/E_{acc} ratios. A second approach consists in suppressing the rounded transition between the coupling

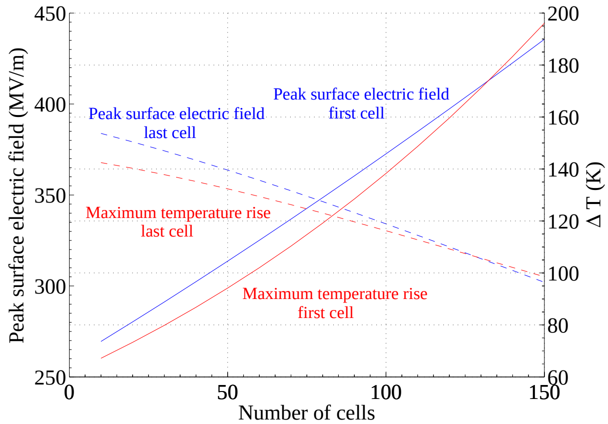

Figure 3: Unloaded peak surface electric field and maximum temperature rises for the first (- -) and last cell (—) vs. number of cells – XDSb.

iris and the waveguide. A structure (XDSc) based on this later consideration (see Figure 4) has been designed, the variation of the cell-to-cell iris thickness and of the width of the waveguide-to-cell-coupling iris along the structure being the same than for the XDSb.

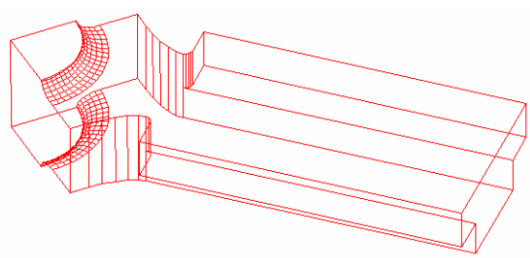

Figure 4: Geometry of the XDSc first cell and damping waveguide.

With a more realistic copper conductivity of 5.51×10^6, a reduction of 5 % compared to the conductivity used in the design of the previous structures, the ratios E_{peak}/E_{acc} are 2.20 and 1.95 for the first and last cells whereas H_{peak}/E_{acc} decreases from 4.51 mA/V to 4.10 mA/V. The Q, R'/Q and v_g/c for the first, middle and last cells are presented in Table 3.

Table 3: Fundamental mode parameters of the first, middle and last cell – XDSc

	Q	R'/Q (kΩ/m)	v_g/c (%)
First cell	3266	24.0	7.61
Middle cell	3260	28.4	5.58
Last cell	3252	33.0	3.83

The unloaded and loaded accelerating gradient and peak surface electric field profiles for a 77-cell structure are shown in Figure 5. The distributions of the peak unloaded surface electric fields and temperature rises are still rather constant, the maxima being 347 MV/m and 122 K, respectively. The RF-to-beam efficiency is 24 % and the required input power per section is 125 MW.

The dipole Qs associated with the lowest dipole band are now 43, 27 and 21 for the first, middle and last cells, and the amplitude of the transverse wakefields at the second bunch is 45 V/pC/mm/m.

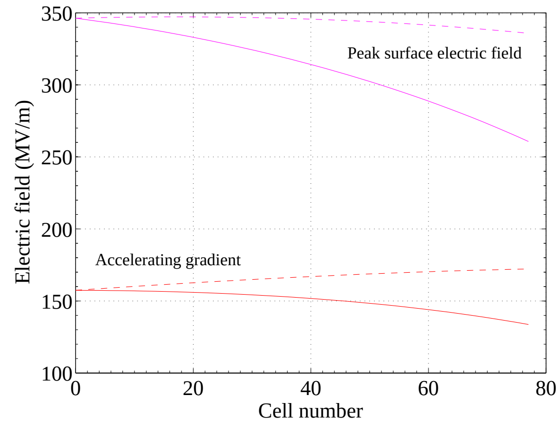

Figure 5: Unloaded (- -) and loaded (—) accelerating gradients and peak surface electric fields – XDSc.

The computed peak surface electric fields are still above the tolerable limit for copper (of the order of 300 MV/m [1]) but seem acceptable for molybdenum [8]. The design of a new structure with cell-to-cell molybdenum irises shows RF performances [9] similar to the one given above. The high pulsed temperature rises are still however an unresolved issue.

4 ACKNOWLEDGEMENTS

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