A NEW DAMPED AND TAPERED ACCELERATING STRUCTURE FOR CLIC

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Abstract

The main performance limits when designing accelerating structures for the Compact Linear Collider (CLIC) for an average accelerating gradient above 100 MV/m are electrical breakdown and material fatigue caused by pulsed surface heating. In addition, for stable beam operation, the structures should have low short-range transverse wakefields and much-reduced transverse and longitudinal long-range wakefields. Two damped and tapered accelerating structures have been designed. The first has an accelerating gradient of 112 MV/m with the surface electrical field limited to 300 MV/m and the maximum temperature increase limited to 100 °C. The second, with an accelerating gradient of 150 MV/m, has a peak surface electrical field of 392 MV/m and a maximum temperature increase of 167 °C. Innovations to the cell and damping waveguide geometry and to the tapering of the structures are presented, and possible further improvements are proposed.

1 INTRODUCTION

The development of a multi-bunch accelerating structure for the CLIC main linac that can operate with an average gradient above 100 MV/m is complicated by the very strict constraints placed on the long- and short-range wakefields. Beam dynamics simulations have shown that to avoid emittance blow-up along the linear collider the amplitude of the transverse wakefield during the first 0.67 ns (the time between bunches in the RF train) must decrease by two orders of magnitude. Such a suppression of transverse wakefields must decrease by two orders of magnitude. Consequently, a further reduction of the transverse wakefields, it is achieved through a combination of detuning and damping. The cell irises radii vary linearly from 2.0 mm to 1.5 mm while the iris thickness is tapered, also linearly, from 0.55 mm to 1.0 mm. The damping is obtained by coupling each cell to four identical T-cross waveguides, the cutoff frequency of the first propagating mode being about 32 GHz, above the 29.985 GHz fundamental but still well below all the higher order modes.

Parametric studies performed on constant-impedance classical accelerating structures (no damping waveguides) revealed that, for a constant iris thickness, the ratio of the peak surface electric field to the accelerating gradient $E_{\text{peak}}/E_{\text{acc}}$, and the ratio of the peak surface magnetic field to the accelerating gradient $H_{\text{peak}}/E_{\text{acc}}$ of the fundamental mode, decrease when the iris aperture is reduced. Moreover, for a fixed iris aperture, an increase of the iris thickness leads to lower $E_{\text{peak}}/E_{\text{acc}}$ but higher $H_{\text{peak}}/E_{\text{acc}}$ [4]. The inspection of the electric field mode pattern on a circularly rounded iris shows that the peak surface field is not located at the tip but is located symmetrically with respect to the plane of symmetry of the iris. Consequently, a further reduction of $E_{\text{peak}}/E_{\text{acc}}$ can be achieved by decreasing the local curvature radius at the position of these maxima, leading to an elliptical profile of the tip of the iris. The reduction of $E_{\text{peak}}/E_{\text{acc}}$ achieved by this means is markedly more pronounced as the iris aperture decreases. The effect on the shunt impedance, on the $\frac{R^/}{Q}$ and on the $Q$ of the fundamental is quite negligible but does slightly effect the group velocity $v_g$.

To reduce the longitudinal and transverse short-range wakefields, it is well known that larger iris radii are more favourable. Moreover, recent studies revealed that large iris radii are also more advantageous for CLIC luminosity be-

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cause of the limitations arising from the damping rings and the beam delivery system [5]. As for the reduction of long-range wakefields, the adopted scheme is a combination of slight detuning and heavy damping. The detuning, which consists in inducing a frequency spread in the dipole bands (the most dangerous higher-order modes belong to the first and second dipole bands), is realized here by tapering the iris radii as well as the iris thicknesses. The damping is achieved by coupling each cell to a set of four radial waveguides. However, due to the broken azimuthal symmetry of the cells, the concentration of the magnetic-field lines in the vicinity of the wide coupling holes leads to a dramatic increase of the ratio $H_{\text{peak}}/E_{\text{acc}}$ if the profile of the outer-cell wall is not optimized. Previous designs had cells with a conventional concave shape of the outer wall. The maximum temperature rise can be brought back to more acceptable values, albeit above the temperature rise of a conventional cell without coupling waveguides, by adopting a convex shape, as a matter of fact a combination of straight and elliptical sections (see Figure 1). However, with an optimized outer-wall shape, larger coupling holes, desirable for more damping, still leads anyway to an increase of the ratio $H_{\text{peak}}/E_{\text{acc}}$.

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

3 DESIGN RESULTS

The geometry of a cell of the XDS structures is shown in Figure 2. The requirement imposed by an acceptable short-range wake level led to an average iris radius $a$ of 1.75 mm with a linear variation from 2 mm at the head of the structure to 1.5 mm at the end. The iris thickness $d$ varies linearly from 0.55 mm to 1 mm. In the absence of coupling waveguides, computations made with URMEL [4] show that the shunt impedance and the $R'/Q$ increases from 113 M$\Omega$/m and 26 k$\Omega$/m, respectively, to 123 M$\Omega$/m and 32 k$\Omega$/m while the $Q$ decreases from 4340 to 3880. The group velocity $v_g$ decreases from 0.086 $c$ to 0.029 $c$. The ratio $H_{\text{peak}}/E_{\text{acc}}$ is fairly constant and is about 3.1 mA/V. The ratio $E_{\text{peak}}/E_{\text{acc}}$ decreases from 2.55 to 1.75 when the ellipticity of the iris shape varies from 1.3 to 1.8.

![Figure 2: Geometry of the XDSs cell and damping waveguides.](image)

The T-cross coupling waveguides and the convex shape of the cell outer wall bring modifications to the fundamental mode characteristics. For the first cell, with a width of coupling hole fixed at 3.0 mm, $R'/Q$, $Q$ and $v_g$ are 25.2 k$\Omega$/m, 3740 and 0.081 $c$, respectively. For the last cell and with the same coupling hole width, $R'/Q$, $Q$ and $v_g$ are 32.1 k$\Omega$/m, 3375 and 0.026 $c$, respectively. Having fixed the widest width of the waveguide to 5.25 mm, the two heights $h_1$ and $h_2$ (see Figure 2) were chosen so that the cutoff frequency of the first propagating mode is between 32 GHz and 32.5 GHz. Whereas $E_{\text{peak}}/E_{\text{acc}}$ is not affected by the damping waveguides, $H_{\text{peak}}/E_{\text{acc}}$ increases to 4.5 mA/V and 4.4 mA/V for the first and last cells, respectively. The distribution of the surface magnetic field normalized to the accelerating gradient $H_{\text{surf}}/E_{\text{acc}}$ for the first cell walls is shown in Figure 3.

![Figure 3: Ratio $H_{\text{surf}}/E_{\text{acc}}$ on the first cell walls of the XDSs](image)
verse impedances associated with the first, middle and last cell of the structures from a FFT of the transverse wakes (Figure 5). The $Q$s for the lowest dipole band, estimated from the transverse wakes, are 52, 51 and 44 for the first, middle and last cells. The transverse wakes of the XDS 1 structure (81 cells) computed in the uncoupled model approximation is shown in Figure 6.

The unloaded and loaded accelerating gradient and peak surface electric field profiles for the two structures are shown in Figure 7. For the XDS 1, with an average loaded accelerating gradient of 112 MV/m, the RF-to-beam efficiency is 32% and the required input power per section is 77 MW. For the XDS 2, the RF-to-beam efficiency is 27% and the input power per section is 132 MW with an average loaded accelerating field of 150 MV/m.

4 FURTHER IMPROVEMENTS

Further improvements in the fundamental mode characteristics can be achieved by rounding the cell outer walls. Preliminary results show an increase in $Q$ of about 10% for the new cells. The resultant decrease in the temperature rise can be as high as 10°C. Complementary studies to estimate the variation of the frequency spread in the dipole bands induced by these modifications and to re-evaluate the damping properties for further reducing the long-range transverse wakes are at present under scrutiny.

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6 REFERENCES