A TAPERED DAMPED ACCELERATING STRUCTURE FOR CLIC

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Abstract

A new 30 GHz multibunch accelerating structure incorporating both damping and detuning has been designed for the Compact LInear Collider (CLIC). Each cell of the 150-cell structure is damped by its own set of four radial waveguides resulting in a *Q* of 16 for the lowest dipole mode. A simple linear taper of the beam-pipe dimension provides a detuning frequency spread of 2 GHz (5.4%). Predictions of the transverse wakefield levels in this structure have been made using both uncoupled, and two-band coupled equivalent circuit models with non-perfect loads. The short-range wakefield has been calculated to be about 1000 V/(pC.mm.m) decreasing to less than 1% at the second bunch (0.67 ns) and with a long time level below 0.1%.

1 INTRODUCTION

The CLIC study of a 0.5 to 5 TeV $e^{\pm}$ linear collider [1] proposes the use of 30 GHz normal-conducting structures operating at high accelerating fields (100 to 200 MV/m) to reduce the length and, in consequence, the cost of the main linacs. In order to reach the required luminosities (10^{34}-10^{35} cm^{-2} sec^{-1}) it is necessary to accelerate and collide multiple bunches per RF pulse. The present CLIC parameter list has 150 bunches each with 4.10^9 particles spaced at 0.67 ns.

The luminosity that can be achieved depends strongly on the vertical emittance at the interaction point. The main source of emittance dilution in CLIC comes from the strong transverse wakefields produced by the accelerating structures. Beam dynamics simulations show that transverse wakefield levels of about 1000 V/(pC.mm.m) decreasing to less than 1% at the second bunch and continuing to decrease thereafter, are required to limit the vertical emittance blow-up along the linac to reasonable values [2]. These wakefield levels cannot be obtained by detuning only, because of a limited bandwidth and recoherence effects [3] nor by a combination of detuning and light damping as proposed for NLC [4]. The required levels were obtained using a structure with four T-cross-sectioned damping waveguides per cell terminated by perfect loads [5]. This structure was considered too difficult to fabricate. It became evident that the problematic stem of the T-shape waveguide could be eliminated if the beneficial detuning effects of a quasi-constant gradient structure were included in the analysis. This has finally resulted in a multi-bunch structure design suitable for CLIC.

2 THE TAPERED DAMPED STRUCTURE

The new structure geometry is shown in Fig. 1. It incorporates both damping and detuning, but does not rely on a high degree of optimization of either. Each cell of the 150-cell structure is damped by its own set of four radial waveguides. The damping waveguides have a rectangular cross-section (4.5 mm x 1.39 mm) with a cut-off frequency above the 30 GHz fundamental but below all higher-order modes. Higher-order mode energy propagates out via the waveguides to small individual RF loads. A taper of the iris dimension from 3.5 mm to 4.5 mm provides a detuning frequency spread of 2 GHz (5.4%) for the lowest dipole mode which helps to decrease the roll-off time. The detuning also plays an important role in reducing the levels of all higher longitudinal and transverse modes.

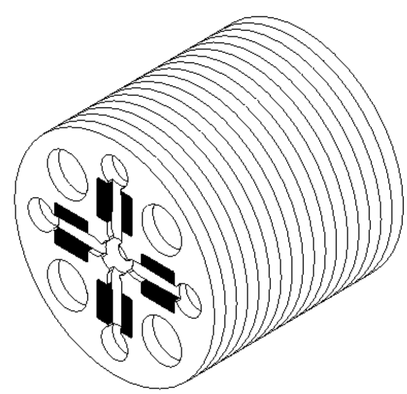

Figure 1: 30 GHz Tapered Damped Structure.

The transverse wakefield of the standard CLIC structure without damping or detuning is dominated by the lowest transverse passband with the higher bands contributing at the 5-10% level. The damping waveguides produce a $Q < 20$ for the lowest dipole band and a $Q \approx 100$ for the next transverse band. The synchronous mode of the lowest band propagates with a velocity of 3% of the speed of light and is attenuated by 5×10^{-3} per cell. The energy does not propagate very far along the structure so the behaviour of this mode can be estimated very well using an uncoupled model.

2.1 Uncoupled-cell analysis

A good estimate of the transverse wake behaviour can be obtained from a simple RLC lumped-element single-cell circuit analysis of the lower band. The values of *L* and *C* were chosen to make the circuit resonant at the synchronous frequency of the equivalent undamped constant impedance (CI) structure with $2a$ = 4mm. From [5] it is known that a Q of 16 is obtained for this mode for the chosen waveguide dimensions. Below cut-off the Q is assumed to be 4000 (the Q of an undamped cell). These effects were simulated in the circuit by an abrupt change of R at cut-off. The Fourier transform of the frequency response of this circuit gives the wakefield time response (Fig. 2). It can be seen that the wakefield does not always decrease exponentially-the long range wakefield is affected by the waveguide cut-off.

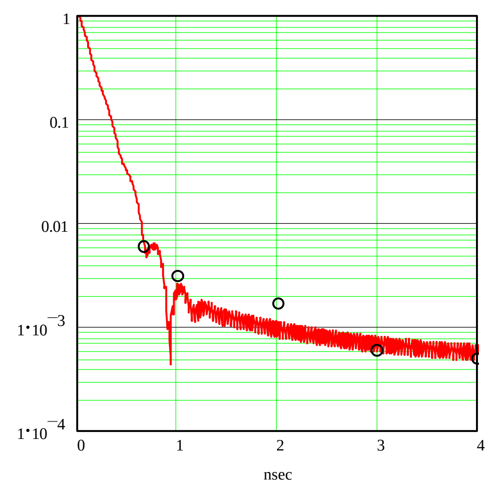

Figure 2: Normalised wakefield using only damping for single-band uncoupled model with perfect loads. (o MAFIA analysis).

Results from a complete MAFIA time-domain multi-cell analysis of the T-waveguide damped CI structure with perfect loads [5] are given in Fig. 2 for comparison. The stem part of the T-waveguide takes out the contribution to the wake of the upper band. The simple model predicts the basic behaviour very well.

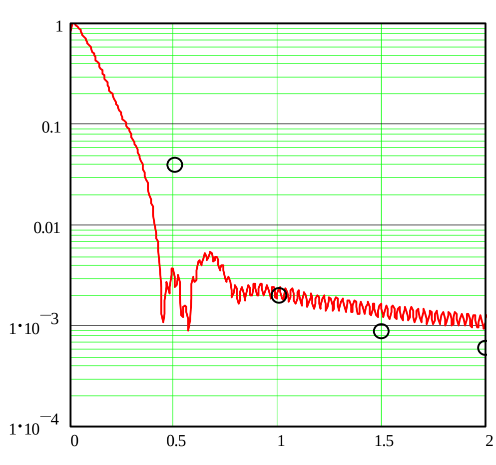

Figure 3: Normalised wakefield with damping and detuning for single-band uncoupled model with perfect loads. (o Two-band coupled-cell results)

The effects of detuning were included by adding the responses of 150 different circuits covering the detuning range ($2a$ = 3.5 mm to 4.5 mm). The wakefield for these damped-detuned uncoupled cells is given in Fig. 3 together with results obtained from a complete two-band coupled-cell analysis (see Section 2.2). To improve the overall model, the upper band of the first pass band which contributes at the 5-10% level to the undiluted wake was treated in the same way as the lower band. The waveguides damp this primarily TE-like mode to a $Q \approx 100$ which alone results in a wakefield level at the second bunch which would be too high. The level is however further reduced by the detuning. As done previously, the responses of 150 different circuits covering the detuning range ($2a$ = 3.5 mm to 4.5 mm) were added to produce the wakefield shown in Fig. 4.

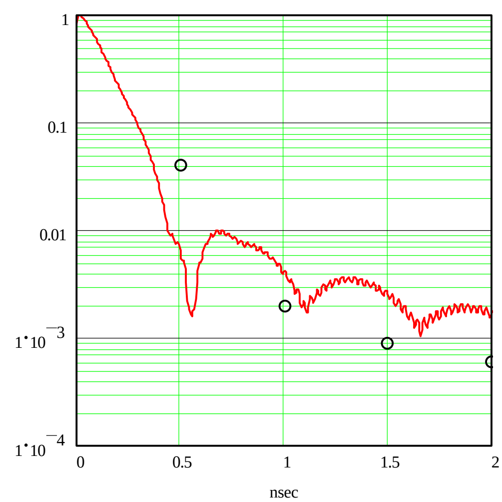

Figure 4: The normalised wakefield with damping and detuning for the double-band uncoupled model with perfect loads. (o Two-band coupled-cell results)

2.2 Coupled-cell double-band analysis

A complete double-band coupled-cell analysis of this new structure has been made using a more complete equivalent circuit model [6]. The damping waveguide, which couples only to the TM part of the circuit, is modeled by a resistor in parallel with the TM inductance. The waveguide load is incorporated into the circuit directly in the form of a table of scattering parameters calculated by MAFIA. The determination of the damped circuit parameters follows the procedures of Bane and Gluckstern [7] for the detuning, and Kroll and Yu [8] for the damping. Circuit voltages are determined as a function of frequency and phase advance by the spectral function method [9]. Calculation of the transverse wakefield from the results of this circuit analysis is not straightforward. For high-Q structures the beam sees a real transverse impedance only at discrete frequencies which are synchronous with the velocity of light. For low-Q structures the resonances spread out such that there is interaction with the beam over a continuous range of phases and frequencies. In this case, the usual Brillouin diagram has to be replaced by a two-dimensional broad-band impedance function depending on frequency and phase advance.

For this particular analysis, the detuning distribution used was not quite linear - it had slight rounding at the ends to improve the long time response, and a conservative value $Q = 200$ was used for the upper-band damping (MAFIA results gave 80 to 130). The load consists of two SiC slabs which sit in the side walls of the waveguide (see Fig. 1) giving a good absorption behaviour close to cut-off. The reflection coefficient data obtained from a MAFIA analysis of this load assuming a dielectric constant of 30 and a loss tangent of 0.5 for all frequencies is given in Fig. 5. The calculated transverse wakefield is given in Fig. 6. The levels obtained are below those determined by beam dynamics simulations for beam stability and good emittance preservation in the CLIC main linac.

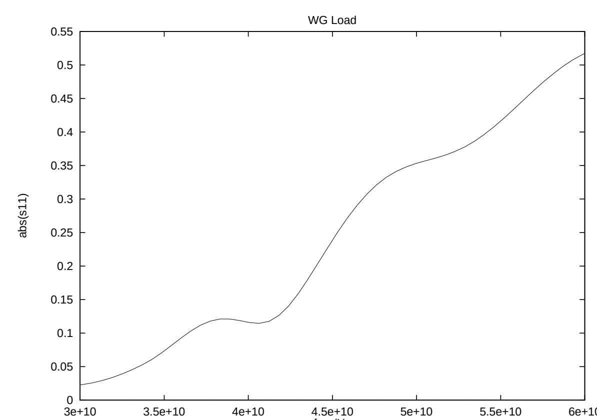

Figure 5: Reflection coefficient versus frequency.

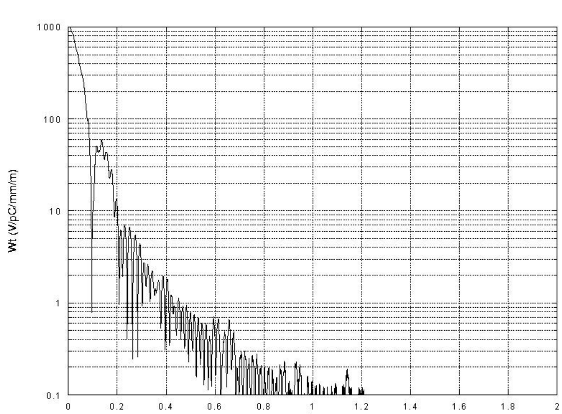

Figure 6: The wakefield obtained for the double-band coupled model plus RF load.

3 CONCLUSIONS

A 30 GHz tapered damped accelerating structure has been designed for CLIC which gives very low transverse wakefields. The wakefield behaviour has been analysed by simple single-cell equivalent circuits assuming perfect loads, and by a very complete two-band coupled-cell analysis with a real load. The single-cell analysis provides a quick and simple way to calculate the wakefield envelope with sufficient accuracy to establish, and study the influence of changing basic design parameters such as the damped Q, detuning range, waveguide cut-off frequency and number of cells. The full analysis is however essential for a detailed design. Cold model tests are presently underway to confirm the calculated values, and prototype structures are foreseen. In particular, it is planned to build an X-band scale model for tests in the ASSET facility at SLAC.

4 REFERENCES

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