FABRICATION AND DESIGN OF THE MAIN LINACS FOR CLIC WITH DAMPED AND DETUNED WAKEFIELD SUPPRESSION AND OPTIMISED SURFACE ELECTROMAGNETIC FIELDS[§]

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Abstract

We report on the suppression of long-range wakefields in the main linacs of the CLIC collider. This structure operates with a 2π/3 phase advance per cell. The wakefield is damped using a combination of detuning the frequencies of beam-excited higher order modes (HOMs) and by light damping through slot-coupled manifolds. This serves as an alternative to the present baseline CLIC design which relies on heavy damping. We report on fabrication details of a structure consisting of 24 cells diffusion bonded together. This design known as CLIC_DDS_A takes into account practical mechanical engineering considerations and is the result of several optimisations since earlier CLIC_DDS designs. This structure is due to be tested for its capacity to sustain high gradients at CERN.

INTRODUCTION

A manifold damped and strongly detuned structure has been studied [1] as an alternative to the present heavily damped main linac structure for CLIC [2]. In order to satisfy the stringent rf breakdown and beam dynamics constrains [2], [3] two main modifications have been made. Firstly, the cavity walls of the DDS structures are changed to an elliptical shape from the standard circular one. This was necessary to reduce the pulsed temperature rise by re-distributing the surface fields [1,4,5]. Secondly, a moderate bandwidth was assigned to the lowest dipole frequencies in order to suppress the beam excited wakefields within allowable limits for a revised inter-bunch spacing of 8 rf cycles (0.67 ns) [5]. Considering the mechanical challenges imposed due to X-band operation (small structures) and breakdown issues pertaining to high gradient, a test structure known as CLIC_DDS_A has been designed to study the fundamental mode properties of this structure at high power operation. For a beam loading of 4.2 x 10^9 particles per bunch at an inter bunch spacing of 8 cycles, the peak input power requirement of this structure is 71 MW to maintain an average accelerating gradient of 100 MV/m. We discuss rf properties of CLIC_DDS_A, an analysis of which is presented in [4-5]. We also report on the wakefield decay in this 24 cell non-interleaved structure. A fully interleaved version of CLIC_ DDS_A suppresses the wakefields well within the level specified by the beam dynamics criteria [5]. Fabrication of this structure is expected to be complete by the last quarter of 2011.

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RF PROPERTIES OF FM AND HOMS

The fundamental mode (FM) rf properties of the structure are presented in [1,4,5] and are summarised in Table 1 together with dipole mode properties.

Table 1: Single Cell RF Properties of CLIC_DDS_A

RF properties	Unit	Value
Accelerating mode properties		
Shunt imp. (In/Out)	MΩ/m	51/118
Group velocity (In/Out)	%	2.07/1.0
Bunch population	10^9	4.2
Peak input power	MW	70.8
Pulse length (t_p^c, t_p^p)[6]	ns	251, 208
Pulsed temperature rise	°K	51
Surface electric field	MV/m	220
Mod. Poynt. Vec. (S_C)	W/μm^2	6.75
RF-beam efficiency (η)	%	23.5
$P_{in} (t_p^p)^{1/3}/C_{in}$ [6]	MWns$^{1/3}$/mm	16.93
Lum. / bunch cross[6]	m^{-2}	1.36x10^{34}
Figure of merit [6]	arb. units	7.6
Lowest dipole mode properties		
Frequency spread Δf	GHz	2.0
Standard deviation	-	σ =Δf/3.48
Detuning spread Δf/f_c	%	11.8

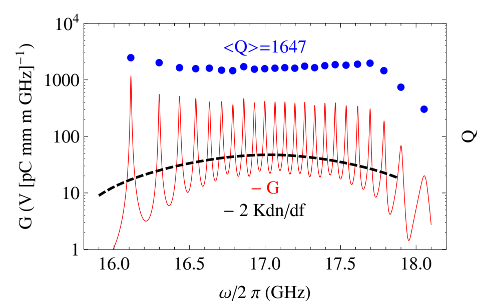

Figure 1: Spectral function, twice kick factor weighted density function (2Kdn/df) and, modal Q.

The manifold slots are optimised mainly to keep the pulsed temperature rise within acceptable limits and in order to efficiently couple out the HOMs. Modifying the manifold slots will enhance the dipole coupling at the cost of the pulsed temperature rise. The spectral function method [7], which calculates the impedance of the structure using circuit parameters [7], has been studied and is displayed in Fig. 1. The width of the spikes in the spectral function indicates the dipole Q of the modes [8].

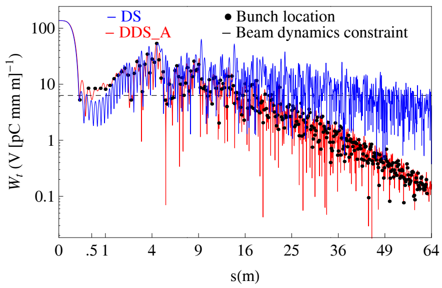

Figure 2: Envelope of wakefield in a non-interleaved CLIC_DDS_A structure compared with a manifold-less detuned structure (DS).

The long-range transverse wakefield in a non-interleaved structure, computed using the circuit model, is displayed in Fig. 2. A complete structure has also been simulated with Gdfidl [9] and this is illustrated in Fig. 3, where it is compared to the circuit model. Even though the low Q of the ends cells (Q~36) is explicitly excluded from the Gdfidl simulations, the agreement is reasonable nonetheless. In either case, it is clear that it is non-adequately damped as the beam dynamics criterion requires it to be below 6.35 V/pC/mm.

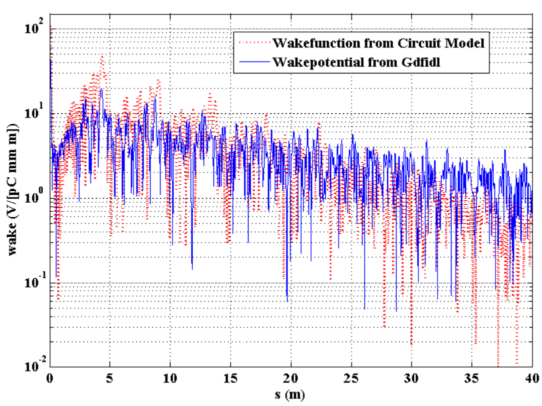

Figure 3: Transverse wakefield computed with Gdfidl (blue) and the circuit model (red).

However, a fully interleaved structure will suppress the wakefields well-within acceptable limits [2-4]. The investigation of the rf parameters is based on a cell subjected to infinitely periodic boundary conditions. Full structure simulations are used to match-out the end cells and to ensure the correct accelerating frequency and phase are obtained. This is discussed in the next section.

END-CELL MATCHING PROCEDURE

An existing mode launcher [10-11] is used to supply power to the structure. It is necessary to match the input and output of CLIC_DDS_A to this device. The matching procedure consists of three fundamental steps:

- A constant impedance structure is used and the end cells are varied to match it out.
- Subsequently the Kroll method [13] is used to minimize the Standing Wave Ratio (SWR) from the output.
- Finally one refines the input match of the full structure.

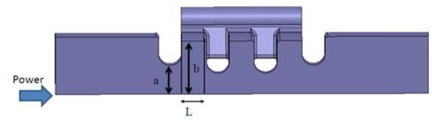

Figure 4: Structure used for the first sub-step of the matching procedure: a and L are varied.

The first step consists of the following sub-steps:

- One builds a structure with one regular cell (namely, first and last regular cell) and two matching cells at each end (see Fig. 4). The minimum value of S_{11} as a function of the geometrical parameters of the matching cells is sought.
- One does the same for a structure with two and three identical regular cells in the middle.
- The matching condition is the one coincident to all three cases (see Fig. 5).

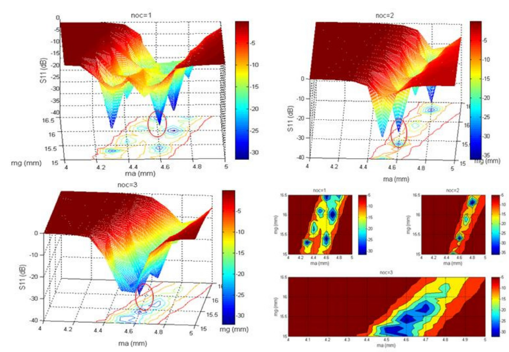

Figure 5: Matching condition for the last cell: only one minimum (encircled in red) is common for all cases.

After the geometrical parameters of the matching cells are assigned, the full structure of 26 cells is simulated. Since the actual structure is not constant impedance, fine tuning is needed. Using the Kroll method, the SWR from the output (see Fig. 6) is minimized. In these simulations copper losses are also taken into account. Reflections at the input are minimized (see Fig. 7).

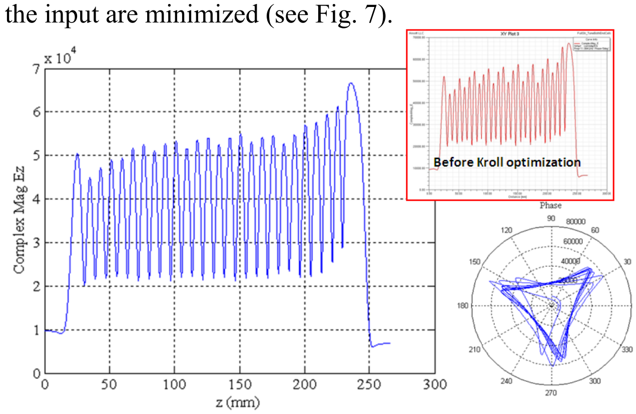

Figure 6: SWR optimization using the Kroll method.

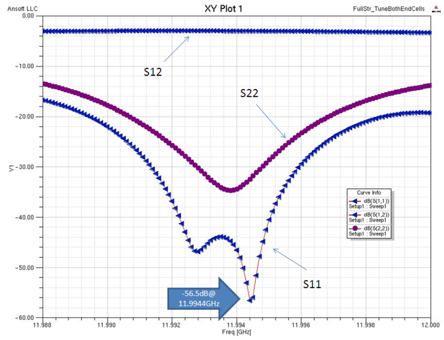

Figure 7: Final S-parameters of CLIC_DDS_A.

The final RF parameters are shown in Table 2. Once fabricated, some slight deviations from these values is expected. The results on surface flatness of recently fabricated cells, together with overall mechanical details, is indicated in the next section.

Table 2: RF Parameters of CLIC_DDS_A.

Parameters	Value	Remarks
Φ_{acc} (Deg.)	120°	$\Delta\Phi_{max}$=6°
f_{acc} [GHz]	11.994	
S_{12}	0.705	
S_{11}	0.004	
t_f [ns]	57.15	
Q_{Cu}	6165	
Gradient averaged over 24 regular cells		
V_{24} [V]@P_{in} = 1 W	2678	L=198.6 mm
G_{24} [V/m]@P_{in} = 1 W	13481	
P_{in} [MW]@<100MV/m>	55.03	

MECHANICAL DETAILS

CLIC_DDS_A will consist of 24 discs and 2 output guide rings, as shown in Fig. 8. The structure terminates

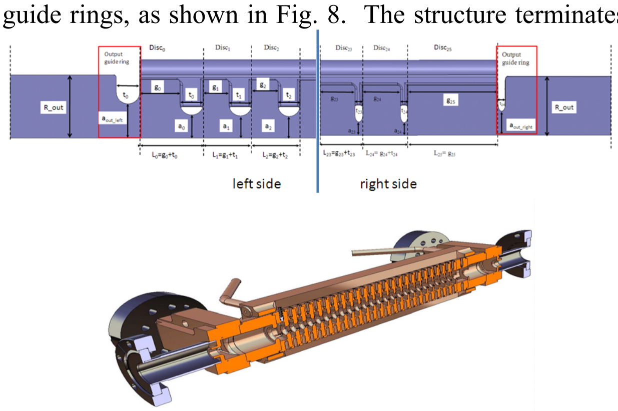

Figure 8: Uppermost: disc subdivision of CLIC_DDS_A; lowermost: 3D-view of full structure.

with mode-launcher type couplers. The possibility of tuning the structure at the accelerating frequency is guaranteed by a dedicated push-pull system inside each disc to facilitate tuning. These high precision discs (± 2.5 µm iris shape accuracy) will be machined with milling and turning, and finally diffusion bonded (requiring a surface flatness accuracy of ~1 µm) under in the presence of hydrogen gas. Four qualification discs have been produced by VDL [13] with the requisite accuracy in shape and surface quality (Fig. 9). Three of these have been successfully bonded by Bodycote [14] (Fig. 9). The full structure will be machined by Morikawa inc. [15] in Japan, in collaboration with CERN and KEK. An initial stack of ten constant impedance cells will be metrological measured and the S-parameters will be rf tested.

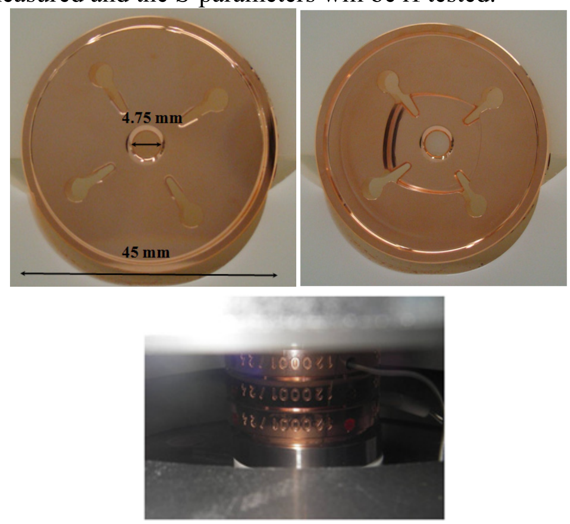

Figure 9: Uppermost: test discs fabricated by VDL; Lowermost: bonded discs fabricated by Bodycote.

FINAL REMARKS

A linac structure which is able to meet the dual requirements of minimal surface electromagnetic fields and well-damped wakefields has been designed. This structure, an alternative design to the CLIC baseline design, employs moderate damping and strong detuning. In order to suppress the wakefields, it relies on interleaving the frequencies of eight successive structures. A single structure is in the process of being fabricated in order to experimentally verify it is able to tolerate high input powers. The design of all cells has been completed, including the matching cells.

REFERENCES

[1] V.F. Khan, *et. al*, IPAC10, 2010.
[2] H. Braun, *et. al*, CLIC-Note764, 2008.
[3] A. Grudiev and W. Wuensch, LINAC08, 2008.
[4] V.F. Khan, *et. al*, to be published, NIMs-A, 2011.
[5] V.F. Khan, PhD thesis, Univ. of Manchester, 2011.
[6] A. Grudiev, *et. al*, PRST-AB, **10**, 102001, 2009.
[7] R.M. Jones, *et. al*, PRST-AB, **9**, 102001, 2006.
[8] R.M. Jones, LINAC04, SLAC-PUB-10682, 2004.
[9] http://www.gdfidl.de/
[10] I. Syratchev, CLIC-Note503, 2002.
[11] C. Nantista, PRST-AB, 7, 072001, 2004.
[12] N. M. Kroll, *et. al*, LINAC00, 2000.
[13] http://www.vdlgroup.com/
[14] http://www.bodycote.com/
[15] http://morikawa-precision.co.jp/