DESIGN OF A CHOKE-MODE DAMPED ACCELERATING STRUCTURE FOR CLIC MAIN LINAC

Jiaru Shi*, Hao Zha†, Alexej Grudiev, Walter Wuensch
CERN, Geneva, Switzerland
Chuanxiang Tang, Huaibi Chen, Wenhui Huang
Tsinghua University, Beijing, China

Abstract

Choke-mode damped accelerating structures are being studied as an alternative to the baseline structure of the compact linear collider (CLIC) by a CERN-Tsinghua collaboration. Choke-mode structures hold the potential for much lower levels of pulsed surface heating and, since milling is not needed, reduced cost. Structures with radial choke attached are simulated in GdfidL to investigate the damping of the transverse wake. The first pass-band of the dipole modes is well damped, while the higher order dipole modes are possibly reflected by the choke. Therefore, the geometry of the choke is tuned to minimize the reflection of these higher order dipole modes. Based on this damping scheme, an accelerating structure with the same iris dimensions as the nominal CLIC design but with choke-mode damping has been designed. A prototype structure will be manufactured and high power tested in the near future.

INTRODUCTION

Waveguide damped structures (WDS) have been chosen as the baseline design for the CLIC main linacs. The CLIC-G design, with small beam apertures and strong waveguide-damping, is now the nominal design in the conceptual design report (CDR)[1]. It operates at 12 GHz with the $2\pi/3$ mode at an accelerating gradient of 100 MV/m. The average beam iris radius of this structure is 0.11λ, where λ is the wavelength, and the average group velocity is $1.3\%\ c$. Though small irises mean higher impedance of the high order modes (HOM's), the strong damping from the waveguides suppresses the transverse kick to a level of < 7 V/pC/mm/m at 0.15 m (6 RF cycles), where the second bunch sits, as required for beam dynamics.

Choke-mode damped structure (CDS) was proposed in the 1990s by Shintake [2, 3] and a C-Band design has been applied to the main linac of the Japanese XFEL project at SPRING-8[4]. The choke design holds the potential of lower levels of pulsed surface heating, which may have a smaller probability of RF breakdown[5]. Meanwhile, since it only needs turning to fabricate, the total cost for building a linac can be reduced.

The choke-mode damping scheme is now studied under the collaboration between CERN and Tsinghua University, which aims at a complete design of an accelerating structure for the main linac of CLIC as an alternative to the baseline design as well as some test structures for high power testing and wake field measurement.

* Jiaru.Shi@cern.ch
† On leave from Tsinghua University, Beijing, China

RADIAL CHOKE

The original design from reference [3] uses a coaxial choke. In this design, there exists a coaxial line with $\lambda/4$ length. The cell length in the design is $3\lambda/8$ ($3\pi/4$-mode structure). So the difference is $\lambda/8$, or 6.5 mm at C-Band. However, for our case at 12 GHz and $2\pi/3$-mode, the cell length is $\lambda/3$ and it is only 2-mm longer than the coaxial choke. Taking into account the gap of the radial transmission line, there is almost no axial space to place a coaxial quarter-wave choke. This point is mechanically weak, and could be a bottleneck for the radial conduction cooling.

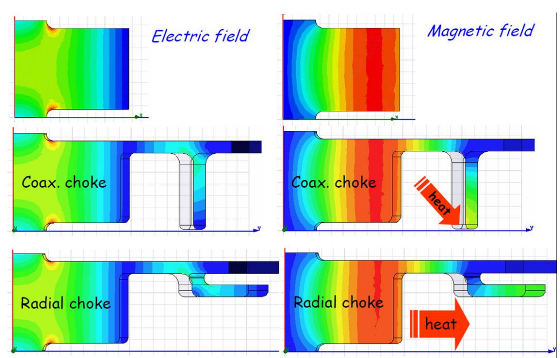

Figure 1: Electromagnetic field of Radial Choke

We come up with a radial choke design which makes a more rigid disk and gives enough space for heat transfer. The cross section is shown in Figure 1, with electromagnetic field plotted. The cell geometry is identical with undamped cells. From the field plot, one can find the field in the cell remains the same as undamped.

RF parameters of different choke gap-sizes are calculated and listed in Table 1. Introducing the choke increases the stored energy in the structure, yielding a smaller R/Q and a smaller group velocity. The Q-factor also decreases, but increases with the gap size, which compensates the decrease of R/Q. The shunt impedance R_s of the choke-mode damped cell is about 60% of undamped cell, and about 80% of that with waveguide damping.

There is no enhancement of surface fields, so the pulsed

Table 1: Comparison of Undamped (ND), Waveguide Damped (WD) and Choke-mode Damped (CD) structure based on the CLIC-G middle cell and with different choke gap size. (Note: ΔT_p is calculated at 250ns, 100MV/m)

		ND	WD	CD-1mm	CD-1.5mm	CD-2mm
Q_0, Cu		6825	5635	4720	5129	5617
v_g/c	(%)	1.32	1.20	1.12	1.04	0.97
R/Q	(kΩ/m)	17.8	16.1	15.2	14.1	13.2
R_s	(MΩ/m)	121.5	90.7	71.7	72.3	74.1
$E_{\max}/E_{\mathrm{acc}}$		1.93	1.93	1.93	1.93	1.93
$H_{\max}/E_{\mathrm{acc}}$	(kA/MV)	2.45	3.85	2.45	2.45	2.45
ΔT_p	(°C)	13	32	13	13	13
HOM 1st band						
f_1	(GHz)	17.82	17.35	16.61	16.20	15.85
A_1	(V/pC/m/mm)	168	156	75	66	82
Q_1		5810	8.7	10.8	14.5	14.3
f_2	(GHz)	–	–	18.06	18.61	19.13
A_2	(V/pC/m/mm)	–	–	146	143	104
Q_2		–	–	8.6	6.8	9.6

surface heating is much lower than that of waveguide damped structure. The CLIC-G design has 47 K temperature rise at the beginning of the structure, where accelerating gradient is about 118 MV/m, while it is only 20 K with choke-mode damping.

WAKEFIELD SIMULATION

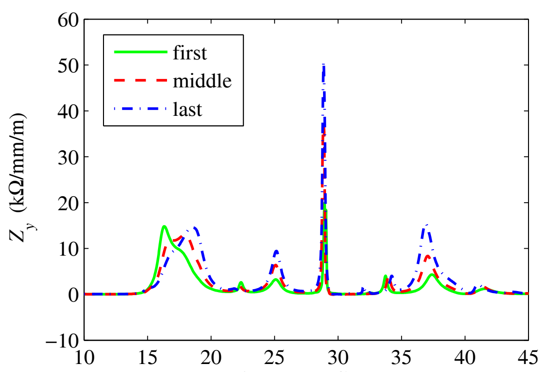

Figure 2: Transverse impedance of "CLIC-G" first, middle and last cell with 1-mm-gap choke

Wakefield calculation is done using GdfidL[6]. The first simulated geometries include 24 identical cells making "constant impedance" structures, taking the cell dimensions from the first, the middle or the last cell of "CLIC-G" design. The absorber in the radial line is replaced with "perfect matched load" (PML) boundary in the code. The transverse impedance of the three types of cells are plotted in Figure 2, normalized by longitudinal length. The impedance of middle cell with different choke gap sizes are plotted in Figure 3.

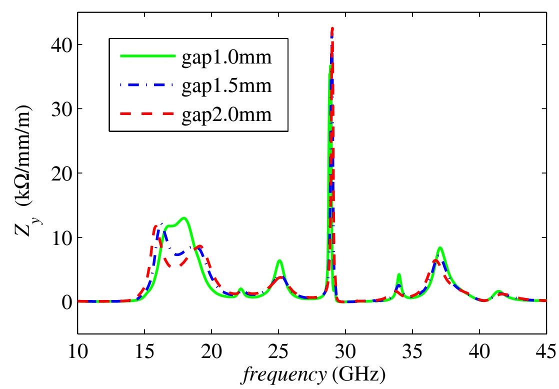

Figure 3: Transverse impedance of "CLIC-G" middle cell with different gap size

By fitting the peak in the spectrum, the amplitude A_n and Q-factor of each mode can be obtained, defined as $W = A_n \exp\left[k_n s(j - 1/2Q_n)\right]$. The Q-factors are very close for same choke size in different cell. But since the last cell has a smaller iris, its impedance is the highest for most of the HOMs.

It can be noticed on the impedance spectrum that the lowest pass-band of the dipole has two peaks; the parameters of this two peaks are listed in Table 1, with a comparison with the waveguide damped structure. The frequency separation increases with a larger gap size, which can be explained by the increased coupling between the mode in the cell and the mode in the choke.

The amplitude of the first HOM, mainly determined by the cell geometry, is very close to that of waveguide damped structure. We also obtain a similar Q-factor with choke-mode damping, which is sufficient. However, there are many higher order modes, especially the one at 28 GHz, being reflected.

The higher order modes have different field profiles in the radial choke from the accelerating mode. Because of the different frequency, the ~30 GHz mode sees zero magnetic field at certain distance from the end of the choke, where the operating mode has a high magnetic field. Adding a perturbation here could tune the HOMs and the working mode to different directions (Figure 4). This effect is plotted in Figure 5 ("tuning-1"). However, the tuning is limited when another higher mode at 37 GHz is pushed up simultaneously and strongly reflected by the choke ("tuning-2" in Figure 5).

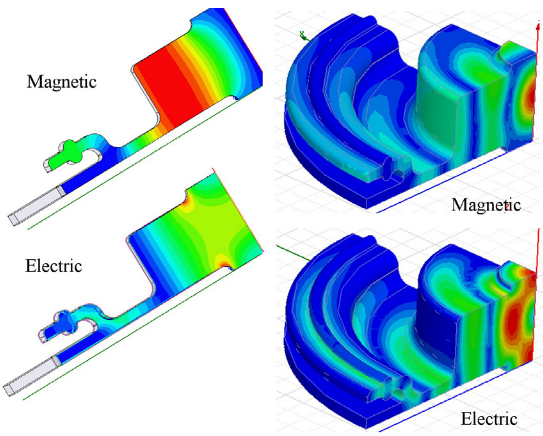

Figure 4: Geometry of HOM tuning and the field profile (Left: Working mode at 12 GHz, Right: Dipole mode at ~30 GHz)

The reduced Q-factor by tuning the choke shows a big effect on the wakefield after 0.3 m. However, it only reduces by a factor of 2 at $s = 0.15$ m, where the second bunch is. A simulation with the tapered structure using the same iris dimensions as the CLIC-G structure but with choke-mode damping is carried out. The wakefields are plotted in Figure 6. The transverse kick at $s = 0.15$ m is ~20 V/pC/mm/m, still ~ 3 times that of waveguide damping design or the beam dynamics requirement.

CONCLUSION

Wakefield simulation shows sufficient damping of the lowest dipole pass-band, and several higher order modes may be suppressed by carefully tuning the choke. Adding constant choke to a tapered structure gives ~20 V/pC/mm/m of transverse kick at second bunch, which is still higher than the beam dynamics requirement (< 7 V/pC/mm/m). Since the choke can be tuned separately from the cells, detuning the HOM's could be a solution to further suppress the wake fields.

In parallel to the wakefield damping study, RF design of a high-power testing prototype (the "TD24-Choke") with input and output matching cells are finished. Future prototypes also include structures with absorbing material filled in the radial lines for wakefield measurement.

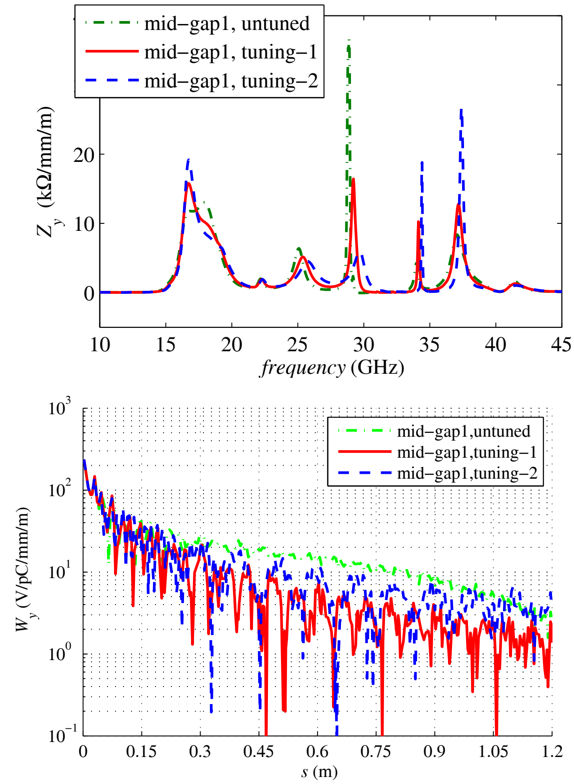

Figure 5: Transverse impedance and wake potential of "CLIC-G middle cell" with 1-mm-gap choke while tuning the choke

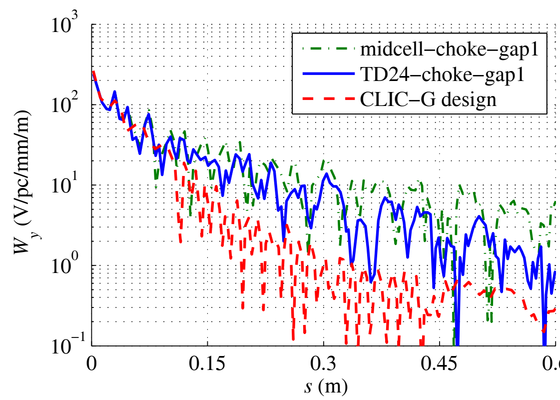

Figure 6: Transverse wake potential of "TD24-choke" with 1-mm-gap choke, compare with CLIC-G design

REFERENCES

[1] A. Grudiev and W. Wuensch, Proc. LINAC10, p211 (2010)

[2] T. Shintake, Jnp. J. Appl. Phys. Vol. 31(1992) pp. L1567-L1570

[3] T. Shintake, Proc. PAC93, p1048 (1993)

[4] T. Shintake, Proc. LINAC10, p1285 (2010)

[5] F. Wang, C. Adolphsen, and C. Nantista, Phys. Rev. ST Accel. Beams 14, 010401 (2011)

[6] W. Bruns, www.gdfidl.de.